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PREFACE.

THE present volume contains nine papers presented at the Annual General Meeting held in London on May 4th to 6th, 1938, together with the discussions and correspondence on them.

The first two days of the Meeting were devoted to a Symposium on Steelmaking; the papers presented to it and the proceedings of the Symposium are printed separately as No. 22 of the Special Report Series of the Institute, and are not recorded in this volume. Special Report No. 20, "The Application of Time Study to Rolling Mills," by the Rolling Mill Committee of the Iron and Steel Industrial Research Council, was also presented at the Meeting, and the discussion on it is included in the present volume. "The Fifth Report of the Corrosion Committee" (Special Report No. 21) was presented formally. A Communication to the Proceedings of the Institute has also been received and this is likewise incorporated in Section I.

As in preceding years, the volume is divided into two main Sections. Section I. opens with the Minutes of Proceedings, including the Report of Council and Statement of Accounts for 1937 and an account of the Annual Dinner; then follow the papers and summaries of the Special Reports presented at the Meeting, together with the discussion and correspondence on them, and also the Communication to the Proceedings not presented to the Meeting.

Section II. is devoted to a survey of the literature on the manufacture and properties of iron and steel and on kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title page is inserted a list of the British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship of the Institute will also be found in the same place.

4, GROSVENOR GARDENS,
LONDON, S.W. 1.
August, 1938.

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Abbreviations used in the Text.

Å.	Ångström unit(s).
A.C.	air-cooled; alternating current.
A.H.	air-hardened.
amp.	ampère(s).
amp.hr.	ampère-hour(s).
atm.	atmosphere(s) (pressure).
Bé.	Baumé (scale).
b.h.p.	brake horse-power.
B.o.T.	Board of Trade.
B.Th.U.	British thermal unit(s).
C.	centigrade (scale).
cal.	calory; calories.
c.c.	cubic centimetre(s).
c.d.	current density.
c.g.s.	centimetre-gramme-second unit(s).
cm.	centimetre(s).
coeff.	coefficient.
const.	constant(s).
c.p.	candle-power.
cu.	cubic.
cwt.	hundredweight(s).
D.C.	direct current.
dia.	diameter(s).
dm.	decimetre(s).
e.m.f.	electromotive force.
F.	Fahrenheit (scale).
ft.	foot; feet.
ft.lb.	foot-pound(s).
g.	gramme(s).
gal.	gallon(s).
H.F.	high-frequency.
h.p.	horse-power.
h.p.hr.	horse-power-hour(s).
hr.	hour(s).
in.	inch; inches.
in.lb.	inch-pound(s).
K.	absolute temperature (Kelvin scale).
kg.	kilogramme(s).
kg.cal.	kilogramme-calory; -calories.
kg.m.	kilogramme-metre(s).
km.	kilometre(s).
kVA.	kilovolt-ampère(s).
kW.	kilowatt(s).
kWh.	kilowatt-hour(s).
lb.	pound(s).
L.F.	low-frequency.
m.	metre(s).
m.amp.	milliampère(s).
mV.	millivolt(s).
max.	maximum.
mg.	milligramme(s).
min.	minimum; minute(s).
ml.	millilitre(s).
mm.	millimetre(s).
m.m.f.	magnetomotive force.
N.	normal (solution).
N.T.P.	normal temperature and pressure.
O.H.	open-hearth; oil-hardened.
O.Q.	oil-quenched.
oz.	ounce(s).
p.d.	potential difference.
*p*H	hydrogen-ion concentration.
r.p.m.	revolutions per minute.
sec.	second(s).
sp. gr.	specific gravity.
sq.	square.
T.	tempered.
temp.	temperature.
V.	volt(s).
VA.	volt-ampère(s).
Wh.	watt-hour(s).
W.Q.	water-quenched.
yd.	yard(s).
°	degree(s).

SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

ANNUAL MEETING

1938

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C., Assistant Secretary, in the preparation of this Section.

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MINUTES OF PROCEEDINGS
AND
PAPERS AND DISCUSSIONS
AT THE
ANNUAL MEETING, 1938.

THE SIXTY-NINTH ANNUAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Institution of Civil Engineers, Great George Street, Westminster, on Wednesday, Thursday and Friday, May 4, 5 and 6, 1938. The first two days were devoted to a Symposium on Steelmaking (Acid and Basic Open-Hearth Practice).

WEDNESDAY MORNING, MAY 4, 1938.

The Meeting opened at 10 A.M. on Wednesday, May 4, 1938. Mr. ALFRED HUTCHINSON, M.A., B.Sc., the retiring President, was in the Chair at the commencement of the Proceedings.

Ballot for the Election of New Members and Associates.

Dr. J. C. HUDSON (Birmingham) and Mr. P. W. WOOD (Consett) were appointed scrutineers of the ballot, and they subsequently reported that the following one hundred and forty-two candidates for membership and twenty-nine candidates for associateship had been duly elected :

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Welcome to Members attending the Meeting, and Greetings.

The RETIRING PRESIDENT (Mr. Alfred Hutchinson) offered a warm welcome to all those attending the Meeting. The programme, he said, was of unusual interest, with a Symposium on Steelmaking for the first two days and the ordinary papers on the third. He was glad to see that some Ladies were present, and hoped that their numbers would increase as the Meeting proceeded.

The Retiring President informed the Members that they had with them that morning one of the oldest members of the Institute, Mr. George Henry Strick, who had joined the Institute in 1876. The Members were delighted to see him present and wished him continued health and happiness. (*Applause.*)

The Retiring President announced that a telegram of greetings had been received from the Verein deutscher Eisenhüttenleute, signed by Dr. Goerens and Dr. Petersen, wishing success to the Meeting; the following is a translation:

To the President, Members of Council and Members of the Iron and Steel Institute and the Staff.

Hearty greetings for the Spring Meeting, with best wishes for its success.

Verein deutscher Eisenhüttenleute, Goerens, Petersen.

His suggestion that the following telegram should be sent in reply was agreed to unanimously:

To the Verein deutscher Eisenhüttenleute, Dr. Goerens and Dr. Petersen.

Sincere thanks for your cordial greetings. These are much appreciated by all attending Annual Meeting of Iron and Steel Institute as token of valued friendship with Verein.

Dudley, Hutchinson, Henderson, Carpenter and Headlam-Morley.

The Retiring President also suggested that a telegram should be sent to Sir Robert Hadfield, who was unable to be present. Sir Robert, who had joined the Institute in 1885, had been President from 1905 to 1907, and was now the senior Past-President. (*Agreed.*) Later a telegram of thanks and appreciation was received from Sir Robert Hadfield.

Presentation of the Report of Council and Statement of Accounts for 1937.

The Retiring President (Mr. Alfred Hutchinson) presented the Report of Council for 1937 (*see* pp. 43 P to 75 P). The membership had increased, he said, from 2,243 to 2,487 during the year, largely as a result of the members nominated by companies and the arrangements for co-operation with the Institute of Metals. Those arrangements with the Institute of Metals were a valuable feature of the work during the past year, and he hoped that closer co-operation between the two bodies would exist in the future. He would impress on heads of works and firms the great importance of allowing the members of their staffs to become Members or Associates of the Institute. It was gratifying to find the increase in membership which had taken place, but there should be a still larger increase in the future.

He called attention to the loss which had been sustained by the death of His Excellency Dr. T. G. Masaryk, Liberator and former President of Czechoslovakia, who became an Honorary Member of the Institute after the Autumn Meeting in Czechoslovakia in 1930. Those who took part in that meeting would remember the great interest which His Excellency showed in the visit, during which he

had invited some of the Members of the Council to visit him at his home. He was greatly interested in the iron and steel industry of his native country and his loss was a heavy one for the industry as well as for the country for which he did so much.

The death had also occurred of Geheimrat Professor Dr. Fritz Wüst, who joined the Institute in 1903 and was elected an Honorary Member in 1931. Dr. Wüst died on March 20, 1938, so that it had not been possible to include his name in the Report. He was the father of metallurgy in Germany, the first Director of the Kaiser-Wilhelm-Institut für Eisenforschung at Düsseldorf, and had been highly respected as a former professor of metallurgy in Aachen. He knew that he was voicing the thoughts of all present when he expressed his sincere condolences to Dr. Wüst's relatives, the Kaiser-Wilhelm-Institut and the Verein deutscher Eisenhüttenleute on the great loss which they had sustained.

Reference was made in the Report to the Autumn Meeting at Middlesbrough last year, and he would like particularly to thank the Committee who had worked so hard in making the arrangements and all those on the North-East Coast who gave the Institute such a splendid time on that occasion. The meeting was a great success. It had been many years since the Institute visited the district, and personally he was most grateful to his friends on the North-East Coast for arranging for the Autumn Meeting during the year of his Presidency to be held in his native district.

Reference was also made in the Report to the transfer of offices. The Members of the Council had felt for some years that the Institute was cribb'd, cabin'd and confin'd in the offices at 28 Victoria Street, and that something must be done. They did their best to try to obtain further accommodation in that building, but it had been impossible to do so. An opportunity was afforded of leasing No. 4 Grosvenor Gardens, as it was being vacated by the American Embassy, and it was decided to take a lease of the property. The building had yet to be put in order, but should be ready to receive the Institute by the end of June. The Council had taken the decision to take a lease of the premises partly because the Institute of Metals had decided to join with the Iron and Steel Institute and make their home there also, and to have a joint library. That would be of great advantage to both Institutes. As President, he would like to say that he felt that the Iron and Steel Institute was greatly indebted to the sub-committee who had undertaken all the arrangements for the new premises, as the work had had to be done at express speed and many meetings were necessary. He would also particularly emphasise the way in which the Secretary of the Institute, Mr. Headlam-Morley, had put his back into the work. (*Applause.*)

Further on in the Report there was a reference to co-operation with local technical societies. Personally, he had taken a great interest in that matter, because he thought that the Institute would greatly benefit if it was possible to foster and take care of those local

institutions. They were not only the nursery from which their Institute should draw its future membership, but they were of great value in the local districts themselves in bringing together the men who were engaged in the industry and giving them the opportunity of discussing technical matters. There was a list of the meetings which had been held, and he thought that the Members would be satisfied that good progress had been made with the holding of local meetings.

He would like to say a word about the Williams Prize. It had been a matter of great regret that for some three years it had not been possible to award that Prize, no paper of sufficient merit conforming to the conditions having been presented. For 1937, however, it had been possible to award the prize for an excellent paper by Mr. W. Geary on " Hot-Metal Practice in Five Melting Shops on the North-East Coast."

With regard to the Library, he hoped that this would increase in usefulness very much indeed when the Institute moved to its new offices. The Institute possessed a magnificent Library, and he doubted whether there was a better one connected with the steel industry anywhere. There would be a far better opportunity of making use of it in the new premises than had been the case in the past.

Mr. JAMES HENDERSON (Honorary Treasurer) presented the Accounts, which were set out in the Report. He did not propose, he said, to go through the figures in any detail, but he hoped that they would receive the attention which they deserved. Turning first to the Balance Sheet, there was no substantial change in the figures, and he did not propose to refer to them in detail. The Balance Sheet was followed by the Income and Expenditure Account for the year 1937. Members' subscriptions were up by £371, and a still further increase was expected as the membership became more effective. The sale of publications was also up by a small amount, and there was an increase in the grant for research from the Iron and Steel Industrial Research Council of £1,000. On the other side, the increased activities of the Institute had called for higher expenditure. The net result was that on the year's working, after taking into consideration the special subscriptions from firms and companies, there had been an excess of income over expenditure of £628, as compared with £224 in the previous year. The remaining pages of the Accounts gave the position of the investments of the various funds, but there was nothing which called for comment. They were all on an extremely healthy basis, and the market value of the securities was considerably in excess of the cost price.

There was one aspect of the Accounts to which he desired to refer. The current year, 1938, would call for a very considerable increase in expenditure in connection with the new home of the

Institute to which the President had referred, an increase both in capital and in current expenses. It would be premature for him at the present stage to suggest any figures, but he must warn the Members that a very great effort must be made to put the financial position of the Institute on a broader and more permanent basis. In saying that, he did not overlook the generosity of companies and firms who had subscribed to the Special Subscriptions Fund.

THE RETIRING PRESIDENT then formally moved the adoption of the Report and Accounts and the motion was seconded by Sir WILLIAM LARKE, K.B.E. (Vice-President), who congratulated the Institute on moving to its new offices—a move which was long overdue. The motion was carried unanimously.

Induction of the President-Elect, The Rt. Hon. the Earl of Dudley, M.C.

The RETIRING PRESIDENT (Mr. Hutchinson) said that his final duty was to induct into the Chair the President of the Institute for the year 1938, the Rt. Hon. the Earl of Dudley, M.C. (*Applause.*) It was a great privilege to him to do so. When he first had to consider the making of steel, as distinct from the making of foundry and forged pig iron, one of the most interesting plants that he visited was Lord Dudley's Round Oak Works at Dudley. There he met Mr. George Hatton, with whom his personal friendship had lasted until the latter's death, and whose sound judgment on all wages questions and on general policy was an admirable asset to his colleagues in the industry. He saw also at those works the Hoesch process in operation, and it was of interest to note that papers to be presented on the present occasion contained descriptions of the up-to-date Hoesch furnace.

Recently Lord Dudley had taken an active part in the modernisation of his own plant, thus taking his share in that extended plan of reorganisation of the technical side of the steel industry which was a complete answer to those critics who told the world that the British iron and steel trade was in a moribund condition. It was hardly necessary to speak of the valuable services which Lord Dudley had rendered to the industry as a whole. He had been President of the British Iron and Steel Federation, and had successfully steered it through a difficult period two years ago. Lord Dudley's ancestors had been deeply interested in scientific research and in the technical development of the blast-furnace and its consequent benefit to the coal trade. It was in keeping with that family tradition that Lord Dudley should have accepted the invitation of the Council to be President of the Institute.

The Institute was particularly fortunate in that Lord Dudley's year of office coincided with the visit to America. Lord Dudley was well known to the American steel industry, and only a month or two ago visited the United States as a member of an important

delegation from the British Iron and Steel Federation. He was confident that American metallurgists and all engaged in the American iron and steel industries would be particularly pleased to greet as President of the Institute such a distinguished member of the House of Lords as Lord Dudley, whom he now asked to take the chair.

Mr. ALFRED HUTCHINSON then vacated the chair, which was taken, amid applause, by the incoming President, the Rt. Hon. the EARL OF DUDLEY, M.C.

The PRESIDENT (Lord Dudley) said that it was hardly necessary to remark that this was one of the proudest moments of his life, to have been invited by the Institute to accept one of the greatest honours which it could bestow on those engaged in the great iron and steel industry. It would be a source of the utmost pride to him to occupy the Presidential Chair of the Institute. Mr. Hutchinson had said many kind but undeserved things about him, and the Members had received them in a most charming way. Mr. Hutchinson referred to the association, which went back for many centuries, of his (Lord Dudley's) family with the iron and steel industry, and he was very sensible of the great pride which they would feel in the honour which had been paid him that day. He could only give the assurance that during his year of office he would do everything that a human being could do, within the limitations of humanity, to further the interests of the great and historic Iron and Steel Institute. (*Applause.*) When he looked at the list of the famous Presidents of the past, he was very much overawed, and his sense of the honour conferred upon him was still more greatly intensified. He felt a particular responsibility by virtue of the fact that he followed one who had proved himself to be such an energetic, such a popular, and such an able President as Mr. Hutchinson, who had just retired from the Chair. (*Applause.*)

Mr. Hutchinson's year of office had been marked by several notable changes in the policy of the Institute, which would prove to be of great benefit to it. In a few moments the Members would have the opportunity of expressing their gratitude to him for the work which he had carried out on their behalf during the past year. He would ask Sir Peter Rylands to propose a vote of thanks to Mr. Hutchinson.

Vote of Thanks to the Retiring President.

Sir W. PETER RYLANDS (Past-President) said he had been a Member of the Institute for nearly forty years, and the recollection of the early period of his association with it which stood out most strongly was the continued presence at every meeting of Mr. Hutchinson and his father. He could not believe that there were other men who had taken a more practical and earnest interest in the work of the Institute than the retiring President and his father. Mr. Hutchinson himself had always taken the keenest interest in every practical

paper presented to the Institute, and his period of office had reflected in a very high degree that practical interest in the welfare and the furtherance of the interests of the technical side of iron and steel.

Mr. Hutchinson had always been particularly interested in practical matters which affected the day-to-day work of the practical steelmaker, and in his term of office which had just concluded he had left his mark in just such a practical way upon the well-being and future prospects of the Iron and Steel Institute. While not maintaining that Mr. Hutchinson was entirely responsible for everything that had been done during the past twelve months, personally he believed that hereafter the Members would look back upon the events of the last twelve months as marking a particularly important stage in the history of the Institute.

Reference had already been made to the scheme for removing the offices of the Institute from Victoria Street to Grosvenor Gardens, and personally he could well believe that that in itself would mark a very important step in the work of the Institute. It had been very difficult for the Institute to conduct its business with efficiency and dignity in its present offices, and it would considerably facilitate the practical side of the Institute's work when it was installed in its new home.

There were other important things for which Mr. Hutchinson had been responsible, one of which was the Symposium on Steelmaking which was about to be held. Personally, he could conceive of no work of the Institute for many years past which would make such a practical appeal to steelmakers as the Symposium.

He would like to point out that for some years past the Treasurer had been suffering from great financial anxiety, and there again it was remarkable that Mr. Hutchinson's period of office had coincided with a marked improvement in the financial position of the Institute.

In conclusion, he would like to say that it was one thing to be elected President of the Institute but it was quite another to carry out the duties in a continuously efficient manner. Mr. Hutchinson had spared himself in no way in attending to the duties of his office, and had attended countless meetings and tried in every possible way to further the well-being and the interests of the Institute. In his capacity as President he had shown that practical interest and enthusiasm which had always characterised him. The Members would therefore wish to carry a most hearty vote of thanks to Mr. Hutchinson for the admirable way in which he had discharged the duties of President and for the incalculable services which he had rendered to the Institute during his year of office.

Mr. F. W. Harbord, C.B.E. (Past-President), who seconded, associated himself with all that Sir Peter Rylands had said about the retiring President. It was only those who were intimately associated with the work of the Council, he said, who knew how much time and work Mr. Hutchinson had devoted to the interests of the Institute.

The vote of thanks was carried with acclamation, the members standing in their places and applauding.

Mr. ALFRED HUTCHINSON said he was almost overwhelmed with the sincerity of the thanks expressed to him. When he took office a year ago, he realised that the Institute had conferred upon him a very great honour indeed, and the oldest Past-President of the Institute sent him a message which touched him very much, wishing him a happy year of office. He was glad to be able to say, at the end of that term of office, that he had had a very happy year. He had enjoyed immensely all the work which he had been able to do for the Institute, and he hoped, and indeed knew, that a very useful year's work had been done under his Presidency by the Council and by all those who had the interests of the Institute at heart and who served it so faithfully.

Something had been said about the removal of the offices. That did involve a great deal of work, but he was certain that the time had come when it had been necessary to decide whether the Institute was to go forward or whether it should gradually slip back, because it could not provide its Members and its officials in its old premises with the accommodation which was becoming increasingly necessary.

He could not sit down without expressing his personal thanks to his Co-Members of the Council for all the help which they had given and the forbearance which they had shown him during his year of office, and he would like in particular to thank the Secretary, Mr. Headlam-Morley, for all the good work that he had done. (*Applause.*) In Mr. Headlam-Morley the Institute had an invaluable and able Secretary, who lived for its success, and he would like to thank Mr. Headlam-Morley personally for all his kindness and attention during the past year. He would also like to thank every member of the staff at 28 Victoria Street. They were a hard-working and able staff who did the Institute great credit, and by their day-to-day work they contributed very materially to its success.

He would like to conclude by thanking the Meeting very heartily for the way in which the vote of thanks had been received. He had retired from the Presidency, but he had no intention whatever of retiring from the Institute, and as long as he lived he would do his best to further its interests. (*Applause.*)

Election of Vice-Presidents and Members of Council.

The SECRETARY said that in accordance with Bye-Law 10 the names of the following Vice-Presidents and Members of Council were announced at the Autumn Meeting, 1937, as being due to retire at the present Annual Meeting :

Vice-Presidents :—Dr. C. H. Desch, Mr. Arthur Dorman, Mr. H. Spence Thomas.

Members of Council :—Dr. T. Swinden, Mr. A. McCance, Mr. P. B. Brown, Mr. A. O. Peech, Captain H. Leighton Davies.

Mr. A. O. Peech having been elected a Vice-President, Mr. I. F. L. Elliot became due to retire in his stead.

No other members having been nominated up to one month previous to the present meeting, the retiring members were now presented for re-election.

The retiring members were unanimously re-elected.

General Remarks by the President.

The PRESIDENT (Lord Dudley) said that the next item on the Agenda was " General Remarks by the President," and under that heading he would like to support what had been said by Mr. Hutchinson with regard to the welcome which the Institute desired to offer to the Ladies present. He would particularly welcome Mrs. Hutchinson and Mr. Hutchinson's daughter. (*Applause.*) The Institute also welcomed all the Lady Members who were present and hoped that their numbers would increase in the years to come. He also wished to extend a welcome to the Members from overseas. The Institute was fully international both in its scope and in its membership, and was always glad to welcome foreign Members at the meetings. He noticed that there were some foreign Members present that day. Some were regular in their attendance at meetings of the Institute, and he hoped that not only would the foreign membership of the Institute increase in future but that those who were already Members would find it possible to follow the example of those who regularly attended the meetings and come over for that purpose as often as possible.

As Mr. Hutchinson had said, he had had an opportunity, in representing the iron and steel industry, to come into very considerable contact, together with his colleagues, with representatives of the industry in all foreign countries, and he had come very definitely to the conclusion that the work in the international field done by members of the industry not only had valuable technical results but was diplomatically one of the most valuable assets imaginable. The way in which the industry worked together was remarkable, and one of the greatest assets for promoting peace and friendship throughout the world. (*Applause.*)

He was particularly fortunate in having stepped into the Presidential Chair at the present time, because the iron and steel industry was still enjoying, he was happy to say, a reasonable measure of prosperity. Moreover, he was taking the Chair at a moment when the domestic affairs of the Institute were particularly happy and prosperous. They were moving into new offices, they were going to America, and there was every indication of their future prosperity. He only hoped that at the end of his year of office he would not find that he had ushered in a period of depression and so go down to history as one of the Jonahs of the Institute. Personally, he had

faith that the clouds which were to be seen in the offing at the present time, which we were reefing down our sails to meet if necessary, would yet roll by, and that the sun would shine again just as brightly in a year's time as it had shone during the past year or two.

He did not wish to go over the ground that had already been so adequately covered by the retiring President in regard to the new office of the Institute, the new Library and so on, but he would like to say that he considered the move an essential and a valuable one. The Institute had occupied its present offices for over fifty-six years, and the accommodation, as had been obvious for some time, was quite inadequate and very inconvenient and uncomfortable for the staff. He felt sure that the move would give the Institute increased virility, and increased encouragement and energy to the Secretary and staff.

He would like to touch on the very valuable co-operation which had been achieved—he might almost refer to it as a treaty which had been signed—with the Institute of Metals, who were to share the new home of the Iron and Steel Institute. That close co-operation between the two Institutes was begun when Sir Harold Carpenter was President of the Iron and Steel Institute, and had been continued with increased momentum since then; and a year ago an arrangement had been made with regard to joint subscriptions which had resulted in over one-fifth of the members of the Iron and Steel Institute now being members also of the Institute of Metals. (*Applause.*) When they got together in their new building they would share the Library, as had already been said, and collaborate in many other ways, while of course each maintaining their identity and independence. He thought it would be the wish of the Meeting that at the present stage he should publicly express the deep gratitude of the Institute to the Council of the Institute of Metals for the very friendly way in which they had conducted their negotiations, and particularly to Mr. W. R. Barclay, O.B.E., the President of the Institute of Metals last year, to Dr. C. H. Desch, the present President, and to the Secretary, Mr. Shaw Scott. (*Applause.*) As was well known, the Institute of Metals were collaborating with the Iron and Steel Institute in the visit to America in the autumn; the two Institutes were to have joint meetings in New York on October 3 and 4. There was every indication so far that those meetings would be successful and well attended. He had been in America recently and had had an opportunity of meeting many of those who were making the arrangements, and he could give the assurance that, with the well-known American hospitality and energy, those in the United States were working very hard to make the visit an outstanding success. He hoped that Members of the Institute, and not only British Members but their foreign colleagues also, would rise to the occasion and take part in the visit to Canada and the United States in large numbers, and that not only would a great number of principals attend—because a great number of American

and Canadian principals were going to take part—but that they would give every facility and encouragement for the younger members of their staffs to accompany the party and take advantage of the programme, which included visits to all the well-known and most up-to-date works in Canada and the United States.

The membership of the Institute, as had already been pointed out, had been well maintained, and indeed increased, and he hoped that there would be a further increase during the coming year not only in the British membership but of foreign Members also. The Honorary Treasurer had referred to financial difficulties, and he hoped that during the forthcoming year it would be possible to come to some arrangements by which the subscriptions would be put on a more permanent basis, so that the financial anxiety which existed at the moment could be dissipated.

Presentation of the Bessemer Gold Medal for 1938 *to Dr. C. H. Desch, F.R.S.*

The President said that his next and very pleasant duty was to present the Bessemer Gold Medal for 1938 to Dr. Cecil Henry Desch, F.R.S. Dr. Desch was so well known to all the Members that it was not necessary to enlarge on his career and achievements.

Dr. C. H. Desch had long been distinguished as a teacher of metallurgical chemistry. He was lecturer in this subject at the University of Glasgow and, subsequently, Professor of Metallurgy at the Royal Technical College, and later at the University of Sheffield, where he succeeded the late Professor Arnold. His text-book on "Metallography" had been for many years the classical publication on this subject in Great Britain. He was a leading authority on the chemistry of solids, upon which he had given a series of lectures recently at the University of Cornell. In 1932 he was appointed to succeed the late Dr. W. Rosenhain, F.R.S., as Superintendent of the Metallurgical Department at the National Physical Laboratory. Since that time he had been in charge of researches which had for their object the production of metals of the highest degree of purity obtainable, for the purposes of research—in particular, the metals of the iron group. Under his leadership, methods had also been worked out for estimating, in a satisfactory manner, the oxygen content of steels. He was a Past-President of the Faraday Society and President of the Institute of Metals.

The President, addressing Dr. Desch, said : It gives me particular pleasure to have the honour of presenting you with this Medal, because you and I have been colleagues on the Council of this Institute for some time, and during that time I have had opportunities of getting to know you and of admiring your great personal qualities, and of realising that a scientist of international repute is also a very charming and delightful man. (*Applause.*) I should like you to know what great and unfeigned pleasure it gives to the Members of the Council and to all the Members of this Institute to

be able to present you with this, the highest honour which it lies in their power to confer upon one of their Members. We present it to you not only as a mark of our personal affection and esteem for you but also in recognition of your important services to metallurgy and to our industry.

We feel that it is peculiarly fortunate that you are, in the year in which you receive this Medal, the President of the Institute of Metals, owing to the fact that we are now in such close and family collaboration with your Institute. This Medal also carries with it our gratitude for and recognition of all that you have done personally in soldering that very happy relationship. I present you with this Medal on behalf of the Council of the Institute with my congratulations and good wishes. (*Applause.*)

Dr. C. H. DESCH said he was profoundly conscious of the great honour done him by the award to him of the Bessemer Gold Medal, the highest award that the Institute was able to make.

It had been for him a very happy chance that he entered the career of metallurgy, in which he had found so much happiness over a number of years. He used the word " chance " advisedly, because he never contemplated becoming a metallurgist, having been trained as an organic chemist and obtaining his practical experience first in the chemistry of brewing, and then in the production of fine chemicals. It was only after his return from Germany, where he had been conducting organic research, that he found himself in the necessity of looking for a new post. Professor Huntington at that time needed a research assistant in metallography. Personally, he knew nothing of the subject, but Professor Huntington had a very good microscope, and his own experience of the microscope had been gained entirely in bacteriology. The number of metallographers at that time, however, was small, and the handicap was not as great as it would be to-day. The only text-book available was a collection of essays published under the name of " L'Étude des Alliages," by Le Chatelier. When any difficulties were encountered, the simplest plan was to write to Dr. Stead, whose vast stores of knowledge were always at the disposal of every young man who cared to send to him for information, and he had been fortunate enough in that way to get into the work of metallurgy, and had never regretted it since.

He was also fortunate in having been trained under a system which did not call for attention to examinations. He attended both a school and a college which stood completely outside the examination system. The amount of chemistry and physics which they did at Finsbury would seem ridiculously small to the modern undergraduate, but what was taught was taught thoroughly, and all who passed through that training regretted that those institutions had had to be abandoned because of the demand for increased examinations and letters to put after one's name, because something was lost in the training of technical men thereby.

He had always enjoyed the most pleasant relations with the industry and with the scientific world connected with metallurgy. The members of the metallurgical industries had always been extremely friendly, and he owed very much indeed to the help of his colleagues in Glasgow, in Sheffield, and at the National Physical Laboratory. He must also acknowledge the very great help which he had received throughout from his wife, originally a colleague and collaborator. He felt that what he had been able to do would never have been done without her help. (*Applause.*)

Allusion had been made to the relations between the two Institutes, the Iron and Steel Institute and the Institute of Metals. Since the kind of work in which he had been engaged had been mainly that of teaching, of collecting the scientific information available and interpreting it to others and encouraging others to do research, he had necessarily found the field of metallurgy a single one, the division into the ferrous and non-ferrous sides being of far less importance in that kind of work than it was in industry. He rejoiced greatly that the relations between the two Institutes were so friendly, and he trusted that the effect of that closer co-operation would be to the benefit of industry generally.

He would like to thank the President for his very kindly greeting, and to thank all the Members and friends in the Institute for the kind reception which they had given him that day. (*Applause.*)

Presentation of the Williams Prize for 1937 *to Mr. W. Geary.*

The PRESIDENT (Lord Dudley) said that the Williams Prize for 1937 had been awarded to Mr. William Geary for his paper on " Hot-Metal Practice in Five Melting Shops on the North-East Coast," which was read at the Autumn Meeting at Middlesbrough. He had very much pleasure, on behalf of the Members of the Institute, in handing to Mr. Geary the Williams Prize. As had already been said that morning by Mr. Hutchinson, the present was the first occasion for three years that the Prize had been awarded, but Mr. Geary's paper was exactly the kind of paper for which the Prize was intended, the kind of practical paper envisaged by the founder of the Prize. He was glad to see that Mr. Geary's example had been very well followed, because in the Symposium some of the papers were modelled on that which Mr. Geary had presented.

The President then, amid applause, handed the Williams Prize for 1937 to Mr. W. Geary, who expressed his keen appreciation of the honour paid to him by the Council in awarding him the Prize.

Presentation of the Presidential Address.

The PRESIDENT (Lord Dudley) then delivered his Presidential Address. The text of this will be found on pp. 77 P to 83 P.

Sir HAROLD CARPENTER, F.R.S. (Past-President), in proposing a vote of thanks to the President for his Address, said there was a certain appropriateness in his doing so, because both Lord Dudley and he had a famous metallurgical ancestor. Lord Dudley's ancestor—and he went back 300 years—represented steel, while his own ancestor, who went back about 160 years, represented iron, so that in their two persons they represented the two metals with which the Institute dealt. It was of interest to notice that in the Lecture Theatre in which the meeting was being held on one side was inscribed the name of Cort while on the other side there was inscribed the name of Dudley, and personally, as a descendant of Cort, he would like to salute the President as the descendant of Dudley.

The President had given a very brief Address, but its quality was not to be judged by its shortness, and he had touched on several important matters on which the Members would do well to ponder. To take only one, the President had referred to the fact that we were a nation of individualists. That was quite true, and personally he hoped that it would always remain so, because individualism was only another word for originality, and it was originality which had made us what we were. The modern problem, as the President said, was to combine that particularly English quality with the modern need for co-operation, and in that connection tribute should be paid to Lord Dudley as a representative of the modern iron and steel industry. In him the Members recognised one who combined the quality of originality with the desire and the capacity to co-operate. The Institute was therefore singularly fortunate in the fact that Lord Dudley had acceded to the wish of the Council and had consented to occupy the Presidential Chair. Although Lord Dudley had been in that Chair for but a short time, it was easy to see that he was in every respect a fully qualified President of the Institute. He was in touch with every part of its activities and its work, and the Members would look forward with the greatest delight and pleasure to his year of office.

Mr. JAMES HENDERSON, who seconded, said that he had no distinguished ancestor on either the one side or on the other, but he represented a great body of opinion which would endorse to the full what Sir Harold Carpenter had said about the President and his Address. They had known the President for a number of years and appreciated his good qualities. As for as was humanly possible, Lord Dudley had arranged for the good work to be carried on.

The vote of thanks was put by Sir Harold Carpenter and carried unanimously, with acclamation, and the PRESIDENT expressed his gratitude for the way in which it had been received.

Complete List of Papers Contributed to the Symposium on Steelmaking.

Glasgow District.

J. G. FAIRGRIEVE and J. GIBSON: "Basic Open-Hearth Practice in Scotland."

J. M. FERGUSON: "Manufacture of Plain Carbon Acid Steels."

R. HAY, J. M. FERGUSON and J. WHITE: "Some Aspects of Slag Control in Melting Practice."

Lancashire District.

J. SINCLAIR KERR, J. V. MORGAN, W. GOLDSBROUGH and D. BINNIE: "Open-Hearth Steelmaking as Practised at the Irlam Works of the Lancashire Steel Corporation, Ltd."

J. W. DANKS and V. W. DAVISON: "The Barrow Hæmatite Steel Company, Ltd."

Lincolnshire District.

J. B. R. BROOKE, S. R. ISAAC and A. ROBINSON: "The Steel Plants of the Frodingham District, Scunthorpe."

A. ROBINSON: "The Appleby-Frodingham Steel Company's Melting Shops."

J. B. R. BROOKE: "John Lysaght, Limited, Normanby Park Steelworks, Scunthorpe."

S. R. ISAAC: "The Redbourn Works Melting Shop of Messrs. Richard Thomas & Co., Ltd."

North-East Coast District.

FRANK BAINBRIDGE, W. GEARY, JAMES WINTER and P. W. WOOD: "Acid and Basic Open-Hearth Practice on the North-East Coast."

JAMES WINTER: "Practice at the Works of the South Durham Steel & Iron Co., Ltd., and Cargo Fleet Iron Co., Ltd."

P. W. WOOD: "Open-Hearth Acid and Basic Processes at Consett."

W. GEARY, L. E. CROOKS and E. DREWERY: "Plant and Practice at Works of Messrs. Dorman Long & Co., Ltd."

FRANK BAINBRIDGE: "The Melting Shop of the Skinningrove Iron Co., Ltd."

Sheffield District.

E. DAWTRY, W. H. HATFIELD, F.R.S., and C. W. WRIGHT: "Acid Siemens Open-Hearth Process."

R. PERCIVAL SMITH: "Making Basic Open-Hearth Steel for Many Purposes."

R. T. LINTERN and R. A. HACKING: "Basic Open-Hearth Steelmaking Practice of the Park Gate Iron and Steel Co., Ltd., Rotherham."

R. J. SARJANT and E. J. BARNES: "Some Experiences in the Design and Control of Open-Hearth Furnaces."

T. SWINDEN and J. H. CHESTERS: "Steelworks Refractories."

South Wales District.

JAMES A. DAVIES: "The Mixed-Gas Melting Shop of Guest Keen Baldwins, East Moors, Cardiff."

R. W. EVANS: "A Tilting Furnace Fired with Cold Coke-Oven Gas."

Physical Chemistry of Steelmaking.

A. MCCANCE: "The Application of Physical Chemistry to Steelmaking."

Correlation of British Open-Hearth Data.

"British Open-Hearth Data and their Correlation." BY THE OPEN-HEARTH COMMITTEE OF THE IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL.

Bibliography (included in the bound volume).

"Bibliography on the Physical Chemistry of the Open-Hearth Process (covering the period 1920 to 1937)." PREPARED BY THE LIBRARY AND INFORMATION OF THE IRON AND STEEL INSTITUTE.

Symposium on Steelmaking.

The PRESIDENT (Lord Dudley) said that the technical discussions on the occasion of the present Meeting would be on somewhat different lines from those which were customary at Meetings of the Institute. Some interesting papers had been submitted, and these would be discussed as usual on the third day of the meeting, but for the remainder of that day and for the following day it was proposed to spend the whole time in discussing various aspects of the papers which had been presented for the Symposium on Steelmaking.

He thought that the Symposium was an innovation which should be encouraged. The papers were all of a high standard, and should be of great interest to those engaged in the practical business of steelmaking. A short time ago there had been considerable correspondence in one of the leading technical journals complaining about the want of so-called practical papers. The Symposium this year might be taken as a very adequate answer to that correspondence. As far as the Symposium was concerned, it had been thought better not to arrange for the individual presentation of papers; there would not be time for this to be done, and it would lead to considerable duplication in the discussion. It had been arranged, therefore, that certain subjects should be discussed, and each of those subjects would be introduced by an individual who would draw attention to references in the various papers and to the problems which appeared to deserve most consideration.

He would like to thank all those who had written papers for the Symposium, and to thank the Committee who had made the arrangements. He wished also to refer to the help which had been given by Mr. Percival Smith, the Chairman of the Open-Hearth Committee, and the members of that Committee, and also to express gratitude for the help given by Sir William Larke, Mr. E. C. Evans and the Technical Department of the British Iron and Steel Federation.

The following subjects for discussion were then presented. The names of those who had agreed to introduce them are stated below:

(1) CORRELATION OF BRITISH OPEN-HEARTH DATA. The paper on "BRITISH OPEN-HEARTH DATA AND THEIR CORRELATION," by the Open-Hearth Committee of the Iron and Steel Industrial Research Council, was presented by Mr. E. C. EVANS. It was arranged that no discussion should take place at the Meeting, but discussion by correspondence was invited.

(2) REFRACTORIES, introduced by Dr. J. H. CHESTERS.

(3) FUEL, introduced by Mr. J. A. DAVIES.

The Meeting then adjourned for lunch.

WEDNESDAY AFTERNOON.

Continuation of the Symposium on Steelmaking.

The meeting was resumed at 2.30 P.M. As the discussion on "Fuel" had not been completed at the morning session it was

continued during the afternoon. At its conclusion the following two further subjects were presented for discussion :

(4) FURNACE DESIGN AND CONTROL, introduced by Dr. R. J. SARJANT.

(5) PIT-SIDE PRACTICE, introduced by Mr. N. H. BACON.

Unfortunately, owing to the lateness of the hour it was not possible to discuss " Pit-Side Practice " at the Meeting; discussion by correspondence was invited.

The Meeting adjourned at 5 P.M. until 10 A.M. on the following day.

THURSDAY MORNING, MAY 5, 1938.

Continuation of the Symposium on Steelmaking.

At this session, which commenced at 10 A.M. under the Chairmanship of the President (Lord Dudley), the following two subjects for discussion were presented :

(6) BASIC STEELMAKING—

(*a*) HOT METAL PRACTICE IN FIXED FURNACES, introduced by MR. W. GEARY.

(*b*) COLD METAL PRACTICE IN FIXED FURNACES, introduced by MR. J. GIBSON.

(*c*) TILTING FURNACE PRACTICE, introduced by Mr. A. ROBINSON.

(7) ACID STEELMAKING, introduced by Mr. T. M. SERVICE.

The three sub-sections of the subject " Basic Steelmaking " were discussed jointly.

The Meeting then adjourned for lunch.

THURSDAY AFTERNOON.

Conclusion of the Symposium on Steelmaking.

On the resumption of the Meeting at 2.30 P.M. the following two papers were presented for joint discussion :

(8) METALLURGY AND PHYSICAL CHEMISTRY OF STEELMAKING—

(*a*) SOME ASPECTS OF SLAG CONTROL IN MELTING PRACTICE, by Professor R. HAY, Dr. J. M. FERGUSON and Dr. J. WHITE.

(*b*) THE APPLICATION OF PHYSICAL CHEMISTRY TO STEELMAKING, by Dr. A. MCCANCE.

Mr. ALFRED HUTCHINSON (Past-President), who occupied the Chair in the unavoidable absence of Lord Dudley, in bringing the session to a close said that the Symposium on Steelmaking had now been concluded. It had been an outstanding success. There had been some indication in the Press that it was very desirable that at meetings of the Iron and Steel Institute more attention should be devoted to practical papers. As one who had been a Member of the Council of the Institute for many years, he would like to give the assurance that it was always the earnest desire of the Members of

the Council that as many practical papers as possible should be read and discussed. There had been some idea, he believed, that the shortage of practical papers was due to some fear on the part of heads of firms that trade secrets might be given away and matters might be discussed the revelation of which was undesirable. Personally, he thought that that was altogether a wrong idea and a delusion, and the very fact that during the Symposium so many practical steelworks managers had come together and had discussed such a wide variety of subjects ought to dispel that idea once and for all.

Whoever conceived the idea of the Symposium had undoubtedly had a brain-wave, and it had been carried out in a thoroughly practical way. He would like especially to thank Dr. Swinden and Mr. Percival Smith for the way in which they had carried out the arrangements and done all they could to make the Symposium a success. (*Applause.*) He would also thank the authors of the papers and those who had presented the different subjects for discussion. The best thanks of the Institute were also due to the Committee which had made the arrangements for the Symposium, and to the Open-Hearth Committee, and especially to their Chairman, Mr. Percival Smith, to whose work the success of the Symposium was largely due. Lastly, he would like to thank the Technical Department of the Iron and Steel Federation, with special reference to Sir William Larke and Mr. E. C. Evans. (*Applause.*)

The entire proceedings of the Symposium on Steelmaking are printed in *Iron and Steel Institute, Special Report No.* 22, 1938.

The meeting adjourned at 4.45 P.M. until 10 A.M. the following day.

Annual Dinner.

The Annual Dinner of the Iron and Steel Institute was held at Grosvenor House, Park Lane, London, S.W.1., on Thursday, May 5, 1938. The Rt. Hon. the Earl of Dudley, M.C., President of the Institute, occupied the Chair, and over eight hundred members and guests were present. The guests included: The Rt. Hon. Sir Thomas Inskip, P.C., C.B.E., M.P., Minister for the Co-ordination of Defence; The Rt. Hon. The Marquis of Willingdon, P.C., G.C.S.I., G.C.M.G., G.C.I.E., Lord Warden of Cinque Ports; His Excellency Baron E. de Cartier de Marchienne, The Belgian Ambassador; The Rt. Hon. Lord Stonehaven, P.C., G.C.M.G., D.S.O., LL.D., President of the Institution of Naval Architects; Baron Beck-Friis, Swedish Chargé d'Affaires; Eng. Vice-Admiral Sir Harold A. Brown, K.C.B., Master General of Ordnance; Sir Charles Bruce-Gardner; Admiral of the Fleet Lord Chatfield, G.C.B., K.C.M.G., C.V.O., First Sea Lord and Chief of the Naval Staff; Mr. B. Clasen, Consul General for Luxemburg; Eng. Rear-Admiral E. J. O'Brien Croker; Sir Andrew Duncan, Chairman of the British Iron and Steel

Federation; Viscount Greenwood of Holbourne, P.C., President of the British Iron and Steel Federation; Brig.-Gen. Hugh Headlam, C.B., C.M.G., D.S.O.; Mr. A. L. Hetherington, C.B.E., Assistant Secretary, Department of Scientific and Industrial Research; Sir Walter B. Jones, Bt.; The Rt. Hon. Lord May of Weybridge, K.B.E.; Colonel F. A. Neill, D.S.O., Master Cutler; His Excellency Baron E. K. Palmstierna, G.C.V.O.; Sir Arthur Pugh, C.B.E.; Mr. E. G. Sahlin, Swedish Consul-General.

The loyal toasts having been honoured, The Rt. Hon. the MARQUIS OF WILLINGDON, P.C., C.G.S.I., G.C.M.G., G.C.I.E., Lord Warden of Cinque Ports, proposed the toast of

The Iron and Steel Institute
and
The Iron and Steel Industries.

In doing so he said : I assure you that I feel it a very great honour and privilege to have the opportunity of proposing this toast, and I want to say at once that I am the worst equipped person possible to fulfil that task, for I have had in the past no close association with the iron and steel industry in this country, nor have I had any reason to have any particular or serious knowledge about that great industry. It is true that in the past I did attach myself to one particular industry, the industry of agriculture, because I was a practical farmer in my youth, but I found it a very unprofitable exercise and I was glad when a beneficent Government dragged me away from agricultural pursuits and sent me on a course of administration. If it had not been for my feelings for Lord Dudley and his family, who have been my close friends for many years, and for his own personal persuasion, I should have certainly declined this invitation on account of my lack of qualifications for the task.

It is true that, thanks to the information which I have received from your Secretary, I know that the Iron and Steel Institute is a very strong and important organisation, international in its character, and which, by collecting and collating all kinds of research which has been carried on in the various countries, has done an immense amount to improve the excellence and efficiency of the iron and steel industry. It is true also that in my years of absence away from my home and on my various travels and during my work I have realised the immense amount which we owe to the iron and steel industry in developing the various countries of the world through railways, through harbours, through hydro-electric and other enterprises, and by supplying machinery for various industries for the development of those countries.

I cannot help remembering that when I was Governor-General of India, and also a Provincial Governor in that Country, there were various occasions on which I used to have to go to open some great industrial enterprise. Having performed the opening ceremony, I

was then taken to look at the works, and taken to some particularly intricate piece of machinery which was carefully explained to me by an expert. I hope that I showed some intelligence in that situation, but I am bound to say that generally the explanation left me so completely bewildered that I knew no more about it in the end than I did at the beginning. (*Laughter.*) It is true also that I have seen much more of industrial life in other countries in the Empire where I have worked than I have in my own home country. I have seen a good deal of the industries in Canada, for example, and I should like to refer to that great organisation of " International Nickel " which has its works in Canada, and to the varous hydro-electric enterprises with which that Dominion abounds.

If I may turn for a moment to India, I should like to mention that, with the exception of jute and cotton, industries as a whole, when I arrived in India 25 years ago, were in a very infantile condition. I saw almost the birth of the great iron and steel industry in India, started by the Tata firm, which had at its head Sir Jamsetji Tata, one of the greatest pioneers of industry who has ever existed in India. (*Applause.*) I also know of the two pillars which were produced many long years ago and which exist at Delhi at this moment, relics of an ancient past, and which are supposed, if our experts are correct, to have been constructed in the fourth or fifth century. They provide clear evidence that iron and steel were produced in India long before they were thought of in this country. When I was Viceroy of India, I had a good deal of correspondence with my old friend Sir Robert Hadfield, who was and is a great expert in iron and steel matters. (*Applause.*) He has always taken a great interest in those pillars, and he tried to induce me to be photographed alongside one of the pillars. My modesty at the time prevented me from accepting his suggestion, but I wish now that I had accepted it in order that, by producing the photograph, I could show you my great interest in iron and steel. (*Laughter.*)

I have referred to the enormous usefulness of the iron and steel industry in the promotion of productive enterprises throughout the world, but I cannot help thinking that when we talk about iron and steel at this juncture our minds turn to armaments. The building up of those weapons of destruction would seem to be the chief preoccupation of the countries of the world to-day. Let me add, in that connection, that our recent Budget has shown us very clearly that we have, and necessarily have, to build up our own armaments to a strength suitable for our purposes, and there is no doubt that that is going to be an extremely heavy burden for us all to bear, but a burden which, as is always the case in this country, will be steadily and surely borne. I can only say that I feel very strongly indeed that we shall bear it not for offensive purposes, for I can truly say that no country in the world has worked harder for peace. We shall bear it purely to secure the safety of our homeland and to be enabled

to fulfil our full responsibilities for all purposes connected with the British Empire. (*Applause.*)

I went out to Bombay in the year 1913 when there was an almost cloudless sky and no sign of any danger on the horizon. A year later the War broke out, with all its awful terrors and consequences. I lived through the period of the War in India, and I was very proud then, and always shall be proud, of the loyalty of the Indian people. (*Applause.*) I remember, too, how much we all hoped—and this, I am sure, applies to everyone in this room—that after we had made all the sacrifices and suffered all the terrors of those four years of war, peace and goodwill would prevail once more throughout the world. When I came home I found, alas, that international conditions were in a most anxious and serious state. I might detain you for a very long time in talking about the reasons for that anxiety and for those conditions, but it is no use talking about the past; we have to look to the present and to the future, and each and every one of us must do our utmost to secure peace, that peace which I believe the whole world desires and which is certainly the desire of this country. (*Applause.*)

I do see a certain ray of light shining now through the world, and I think that we ought to be extremely grateful to our Prime Minister for the courage and vision with which he has exercised his personal influence on the international situation at this moment, of which the results has been the securing of a friendly agreement with Italy and the disappearance of our difference with our neighbour, the Free State of Ireland. (*Applause.*) I can talk quite freely on these matters, because I have now no political affinities, and I should like to say that I am glad that our Prime Minister is surviving, and I think even thriving on almost an avalanche of votes of censure in the House of Commons. Personally, I think that those votes of censure were very undesirable and unnecessary in the present conditions.

Meanwhile, may I say that in my view a great responsibility lies on the iron and steel industry to assist in every way to fulfil the programme which we have before us. In wishing them every possible success, prosperity and further activity in the future, I should like to express my conviction that they will take their full part in assisting in the defence of our shores.

It is my privilege and great pleasure to couple with this toast the name of my very good friend the Earl of Dudley, and, as an old friend, I should like to congratulate him warmly on the fact that so early in his career he has arrived at such an extremely prominent position in the world of commerce and industry in this country. I hope that he may be spared for many long years in health and strength to do useful, and I believe brilliant, service for his King, for the country and for the British Empire. (*Applause.*)

The Rt. Hon. the EARL OF DUDLEY, M.C., President of the Institute, who responded, said: Lord Willingdon has just proposed the

health of the Iron and Steel Institute and the iron and steel industries in a very charming and eloquent manner, and it is a delightful privilege to all the Members of the Institute to welcome this evening such an experienced and distinguished proconsul. Although he has excused himself on the ground of ignorance of the technicalities of our industry, it may be of some comfort to him to know that here am I, the President of an Institute concerned with the greatest scientific industry in the world, yet bound to confess that I know as little in regard to the true application of the Bunsen burner as I did on the first day that I walked into the "stinks laboratory" at Eton, though I still have as much fun out of its misapplication as we had in those days. (*Laughter.*) At any rate, we in our humble sphere can learn much from Lord Willingdon's vast knowledge of the world and of those who inhabit it, and from the example which he sets of high and dignified conduct, which can be of great value to us in our commercial and scientific contacts with our overseas Empire and with foreign countries. Lord Willingdon, who has deservedly been the recipient of honours throughout his life, will be able to appreciate my own feelings of pride in having been invited to occupy this Presidential Chair and invested with the duties of replying to this toast, one of the highest compliments which can be paid to me by my colleagues in this great industry. Before replying to the toast, therefore, I should like to take this opportunity of thanking them all for this high honour, and of expressing my eagerness to be worthy of their trust and to discharge my duties throughout the year of my Presidency in a manner which may be comparable to the conduct of a long line of distinguished predecessors in office.

The first thing that I want to do is to express a very warm welcome to all our foreign Members. (*Applause.*) This Institute is international in its scope and in its membership, and I hope that during my year of office our foreign membership will increase, and that we shall have the opportunity of welcoming not only those who regularly attend our meetings but many others also. It is by means of the international exchange of ideas that true value can be obtained from this Institute and from similar bodies in other steelmaking countries.

This year will be a notable one, in the first place by reason of the fact that it will include the first visit of the Institute to Canada and the United States since 1904. We are to be the guests in America of the Canadian Institute of Mining and Metallurgy, the American Iron and Steel Institute and the American Institute of Mining and Metallurgical Engineers. The visit will be an enjoyable one from a social point of view—an important consideration, particularly as Ladies are accompanying us—as I am sure that the well-known hospitality of our cousins across the Atlantic will be stretched to the fullest extent, and it will also be full of interest on account of the many historic and beautiful places which are to be visited. Moreover, it will give our technicians an opportunity of studying at first

hand and in the most up-to-date plants all those great developments which have taken place in recent years in iron and steel manufacture on that great Continent. Above all, it will enable us to consolidate in the firmest possible manner, and under ideal conditions, those relationships and understandings with Canadian and American steel-makers which have always been cordial, but which are of such paramount importance at the present time. I am glad to be able to announce that there is every indication of a record attendance and, in railway parlance, I would give you the strong advice to book early. (*Laughter.*)

I must mention also the further progress which has recently been made in the co-operation with our friends the Institute of Metals, who are accompanying us on this visit and who are going to be co-habitants with us at our new offices in Grosvenor Gardens. (*Applause.*) This collaboration must be a step in the right direction, as I am sure you will agree, because our interests overlap in so many directions, and metallurgy is a science common to us both. As you know, an arrangement for a joint subscription came into force last year, with the result that one-fifth of our Members are now also Members of the Institute of Metals. Although in the future we shall share a large number of activities, both Institutes will, of course, maintain their own identity and their own independence.

I should like to thank Lord Willingdon most sincerely on behalf of all my colleagues for the cordial manner in which he has proposed our health. This Institute has made, during the seventy years of its life, invaluable contributions to iron and steel manufacture throughout the world. Although research has always been an essential branch of its activities, it has always stood also for progress in the practical as well as the scientific side. In these days, when research is of paramount importance in our industry, when within the span of living memory the laboratory has developed from the least important to the most essential unit in the steel plants of the world, the Institute must continue to play an increasingly responsible rôle and ensure that Great Britain retains that pride of place in the scientific universe which we have so far held, and which our national prestige and indeed our national safety demand.

It is now my pleasant duty to propose the toast of

His Majesty's Government

and to couple with it the name of Sir Thomas Inskip. (*Applause.*) Sir Thomas, by reason of pressure of Government business, had to disappoint us recently at the dinner of the British Iron and Steel Federation, and we are delighted to have the opportunity of welcoming him here this evening. I turn to Lord Greenwood without any sense of victory, but with the old saying in mind that what is one man's meat is another man's poison, and what Lord Greenwood lost at his dinner I have gained at mine ! (*Laughter.*)

We are delighted indeed to welcome Sir Thomas here this evening.

As long as the armament programme lasts, collaboration between his Department and our industry must be very close indeed, and it is essential that we should understand and sympathise to the full with each other's problems. Sir Thomas will, I am sure, be the first to admit the vitally important bearing which our industry has upon national safety. I hope that he will be able to tell us this evening that he, from his experience, is satisfied with our ability to discharge those responsibilities and obligations as far as the security of the nation is concerned, and that we are not likely to fall short of any responsibility that he may impose upon us. It is my duty also, I think, to assure him on your behalf this evening that the steel industry is fully sensible of those responsibilities, and to express our unconditional willingness and determination to carry them out in the national interest in any way which he may direct. (*Applause.*)

The fact is that the point has been reached where the whole industry is not only on a sound financial footing for the first time in the last ten years (*laughter*)—I am referring to the balance sheets of individual firms, not to the price of their ordinary shares on the Stock Exchange—but also where British plants are second to none in the world as regards economic manufacture, up-to-dateness and efficiency. At least £30,000,000 has been spent upon them in the last five years, and the present layout and location of our works are eminently suited to a very rapid stepping-up in production if need be. Steelmakers have increased their output capacity during the past two years by at least 3,000,000 tons per annum, and by the end of the current year we shall have raised that capacity by a further 1,000,000 tons. That will exceed by 4,250,000 tons the highest output required of us during the last war. (*Applause.*) It also means that at any moment we can take on a considerable armament load without to any great extent disappointing commercial demands, though it may still involve giving preference to Government over commercial demands.

The Special Supplies Committee set up last year by the British Iron and Steel Federation secures this condition without imposing any compulsory priorities, and the three Defence Departments have expressed themselves as completely satisfied with the arrangement, which has also proved most helpful to private buyers. This Committee is being kept in existence, although difficulties in regard to supplies have now been greatly minimised. They have powers to co-opt representatives of any section of the industry, and in them may well lie the nucleus of the rapid mobilisation of steelmaking supplies in a moment of emergency.

We do not lose sight in the steel industry of the fact that this regeneration of our industry is largely due to the far-sighted policy of His Majesty's Government. When they applied their tariff policy to our industry, they naturally had in mind the necessity of a prosperous and live steel industry for national safety, and by setting up the Import Duties Advisory Committee they ensured, moreover,

with the voluntary consent of the industry, that such policy should be adapted and adopted in an intelligent and flexible way, protecting not only the home industry but the interests of all consumers, including the Government as well. I do want to make that point very clear, because one still hears from some laymen the old profiteering charge against the steel industry, and particularly in regard to the rearmament programme; but the Import Duties Advisory Committee sees to that! (*Laughter.*) I should like to remind laymen that that imposition is in no way statutory, but voluntarily agreed to by the iron and steel industry. I think that with the help of Lord May and his colleagues, whom we are very glad to welcome here this evening, Sir Thomas will admit that that foresight has been fully justified.

I do not wish to resume my seat without making reference to the friendly spirit of collaboration which the iron and steel industry has always experienced in its relations with all those Government Departments with which it has to deal, and I should like to express our deep gratitude for the unfailing courtesy and assistance which we continually receive from those who staff them. They unfailingly apply their minds to the understanding of our difficulties and problems and in return we do our utmost to understand and to sympathise with theirs. In my opinion, this healthy spirit lubricates the mighty machinery of British constitutional government. It is our greatest national asset, and for its existence we are deeply indebted to that wonderful body, the British Civil Service, as well as to their masters, His Majesty's Government. (*Applause.*)

The Rt. Hon. Sir THOMAS INSKIP, P.C., M.P., Minister for the Co-ordination of Defence, who responded, said: My first word must be to thank you, Sir, for the words, as kind as any to which I have listened, with regard to the part which the Government has played in connection with your great industry, and I thank you also for the honour of coupling my name with this toast. You have referred to the fact that I was prevented by some duty in the House of Commons from attending the dinner of the British Iron and Steel Federation. I can almost forgive you for having imposed on me the task of speaking to-night, after I had avoided that duty on that other occasion, when I recollect the words which you addressed to us with regard to the Government.

The strong, silent man is supposed to be everybody's ideal, but there is no place for him in our political system. (*Laughter.*) A Minister is expected to speak on almost every occasion, whether he has anything worth saying or not. He cannot even play an innocent and probably very bad game of golf without being photographed. I have sometimes wondered what on earth is the news value of a member of the Government. If I may take my own case, although I am called upon to speak much more often than I and my audiences like (*laughter*), my candid friends tell me that my speeches

are as ponderous as myself, and no one can say that my figure is cast in a classical mould (*laughter*); yet Lord Dudley says that he was disappointed at my inability to be present at the Federation dinner a few weeks ago!

It is some relief to think that I have an easy toast to speak to this evening. Everyone here to-night is aware, of course, of the virtues of His Majesty's Government. It is a thoroughly popular toast! (*Laughter.*) Have not His Majesty's Government just done their best to balance the Budget? (*Laughter.*) I dare say that some of us wish that we could balance our own budgets by using the same methods that the Chancellor of the Exchequer has employed! (*Laughter.*) Moreover, His Majesty's Government has developed an unsuspected capacity for making treaties, showing what a nice, friendly, generous Government it is. I expect the next thing will be that Mr. Chamberlain and Mr. Attlee will make a treaty of peace and *bon voisinage*. (*Laughter.*) Finally, to add one more wreath to those which already encircle the brow of His Majesty's Government, we have thoroughly justified the name of "national" by nationalising the coal royalties. Lord Dudley says "Not yet!" (*Laughter.*)

With these outstanding achievements to its credit, His Majesty's Government needs no speech from me in its support. It represents the real popular front! (*Laughter.*)

I am no doubt expected to keep off politics before an audience to whom I can sell nothing in that line (*laughter*), but I must be allowed to refer with some satisfaction to a statement made by a Member of Parliament who is the Chairman of a great engineering company, when addressing his shareholders a few days ago. The Member of Parliament in question belongs to the Labour Party, but he thought it proper to complete some observations to his shareholders by assuring them that his own political activities had nothing to do with the policy followed within the works, which would continue to be controlled by the Board in an enlightened and progressive spirit. (*Loud laughter.*)

Politics being barred this evening, and being incapable of post-prandial anecdote, I had better address myself to what is left, and that is iron and steel. I have taken great pains to qualify myself for this task this evening; I have read batches of statistics, and I have made myself familiar with all the proper terms. I have learned to say "recession" when I mean a slump. (*Laughter.*) I have taught myself to say "cartel" when I mean a ring. (*Loud laughter.*) I have practised before a looking-glass saying "Idac" when I mean Lord May. (*Laughter.*) Thus fully armed, I can face this terrifying occasion, and I am bound to say that, though more fully informed about your activities, I cannot claim to be any wiser, and therefore I had better confine my remarks to a few rudimentary facts—and I only hope that they are facts. (*Laughter.*)

The first is that, as we have already been reminded by the

Chairman, iron and steel are an essential part of the structure of our industrial and national system. Nothing could be more obvious and elementary than that truth, but it seems to have been sadly forgotten in the decade to which the Chairman has referred. In 1932 I found from my statistics that pig iron production faded away like the Cheshire cat until a production of 10¼ million tons in the last year before the War stood at only 3½ million tons. Steel ingots and castings, at 5¼ million tons in 1932, turned out to be more than 7 million tons short of our actual requirements in 1937. It is to be hoped that it is not beyond the resources of a modern state to prevent any repetition of that experience. (*Applause.*) The nation which allows that sort of thing to happen, preferring to pay hundreds of millions of pounds to support men who are compelled to be idle, has no right to complain of a delay in producing armaments due to a shortage of steel. I am happy to agree, however, as we all do, with what the Chairman has said about the beneficent work of the Import Duties Advisory Committee. We seem to have reached a condition of flexibility in our iron and steel organisation which augurs very well for the years in front of us.

The second of my trite observations is that you cannot expect an industry to be healthy if you starve it. It is a very satisfactory feature that this industry is now on a parity with that of foreign countries. Ten years ago it would not have been possible to say that, and there was a Government Committee which reported that few British works in the iron and steel industry were then modern in equipment or practice. You have changed all that, but how has it been done? The Chairman referred to the fact that £30,000,000 have been spent on the industry in equipping it in the last few years, and a good deal more will be spent in the present year. That has not come out of anything except the properly earned profits which are as necessary for the purpose of forming reserves as for the purpose of distributing dividends. I venture to add a moral to this observation, that people who complain of blast-furnaces at present being put out must not interfere with the accumulation of the proper reserves to tide over the evil day.

My third and last observation is this. Imports should not be allowed to control and dictate to our home production. Imports make a bad master, as we have found in the past, but a very good servant if properly used. I am sometimes apprehensive about the gap between capacity and requirements if there should be a sudden expansion of the requirements in an emergency. Last year that gap, in peace-time, was filled only by a rapid expansion of imports. Now that market conditions are normal, I think you may rightly expect imports to diminish, and I hope that that will aid the continued prosperity of your industry by the development of our British resources. I see no reason why a period of further prosperity should not lie ahead of the industry. The Institute and the Federation are doing the proper and necessary work on the research and scientific

side. A large volume of industrial work, added to the demand for naval and military purposes, ought to provide a satisfactory market for your products, and I hope that there will be no disposition on your part to act and behave as though the three or four years through which you have just passed, which have enabled you to put your industry into a more prosperous condition than it has been in for ten years past, were a closed chapter. Defeatism is as bad in the industrial as in the military sphere, and vigour and enterprise will reap their reward if, with the advantages which you have already reaped, you go forward to yet further achievements.

I should like to thank the Chairman and all of you for the full measure of co-operation which we have received in the organisation of the national resources for the purposes of defence. I remember that when I was able to set up the Liaison Committee to which the Chairman has referred, composed of representatives of the Government Departments and of the industry—a Committee which has done admirable work in securing the necessary supplies in a period of shortage—I received a generous response to my appeal for a gentleman's agreement for priority for the rearmament programme, a generous and effective response which met the needs of the nation at a very difficult time. This is one of the few places where I can address these most sincere and heartfelt words of thanks to those who are responsible for that happy result.

There is one other thing which I should like to say. I am happy to tell you that in the last day or two—indeed only yesterday—the Amalgamated Engineering Union agreed to meet the representatives of the employers in the engineering industry to consider the steps that should be taken to provide the necessary labour, and skilled labour in particular, for the rearmament programme. I dare say that there would have been a swifter response to the appeal which I made if I had been able to make it in more eloquent and more sympathetic terms; but I cannot do more than I am capable of doing, and I dare say that I was less impressive and less emotional than I should have been. However, there is now agreement to meet the employers, and I am certain that now that a start has been made we shall experience what we have always found in our English history in a moment of emergency, namely, political opinions and private prejudice taking second place to the consideration of the national emergency. I hope and expect that there will be a whole-hearted response both from employers and from labour to the appeal which not I but the nation makes to those who have the capacity to help. That is and has always been our English way, and His Majesty's Government are looking hopefully for a repetition of the common experience in this new emergency.

I thank you on behalf of His Majesty's Government for the kindness of the welcome which you have given to me to-night and for the co-operation which you have already given and will continue to give me in the future. (*Applause.*)

Mr. W. R. LYSAGHT, C.B.E., Past-President of the Iron and Steel Institute, then proposed the toast of

The Guests.

He said: I have the honour to propose this evening the toast of the Guests, and to couple it with the name of His Excellency Baron de Cartier de Marchienne—a lovely name! He has been with us now in this country for eleven years, and has endeared himself to everyone with whom he has come in contact. With gentlemen like His Excellency to represent Belgium, the friendly feeling which exists between our two countries will long remain. Great Britain and Belgium have always been generous friends, and we hope that that friendship will long continue. There are present this evening many people who have the friendliest remembrances of Belgium and her people. I had the honour of being President of this Institute a few years ago when we visited Belgium, and nothing could exceed the hospitality which we received there. (*Applause.*) We were shown everything, and we returned full of admiration for that delightful little country and its extremely up-to-date iron and steel industry. It was my sad privilege on that occasion to lay a wreath on the spot where King Albert met with his fatal accident. The late King Albert was very friendly towards this country, and was an Honorary Member of this Institute, and we can say the same of his son.

Then we have with us to-night Sir Thomas Inskip, to whose inspiring speech we have just been listening, and who is one of the busiest men in the country. The witty speech which he made to us may have been due to some extent to a desire on his part to hide the anxiety which he must have felt when he looked round our care-free faces to-night; he may have been inclined to paraphrase Marlowe by saying "Are these the face that launched a thousand ships and burned the topmost towers of Ilium?" I feel that he may have been inclined to shake his head (*laughter*), but I can assure him that the faces that he sees around him to-night are not the same faces that we show in our works; there our chins are firmer, our mouths are set, our eyes are sparkling and every line on our foreheads does its duty. (*Laughter.*)

Then we have with us the Marquis of Willingdon, to whose delightful speech we listened with so much pleasure. When I read of all that he has done I feel like the man who, on seeing a giraffe for the first time, said "I don't believe it." (*Laughter.*) After being at Eton and the University he has held the highest posts which this country can offer; he has been Governor-General of Canada and Viceroy of India, an experience which has fallen to few men. He has an extraordinary gift of popularity. His remarkable fitness is proved by the fact that he has remained unwaveringly at ten stone seven. He has an admirable memory for faces and a deep sense of humour. He is extremely conscientious, and retains an

aristocratic taste for a glass of port and a biscuit at mid-day and a pint of champagne at night. He never suggests for an instant that he has been both Viceroy and Governor-General. He listens more freely than he talks, and only by his appearance could you guess that he is one of the greatest Englishmen of his age. (*Applause.*)

We have many other distinguished guests with us. Lord Dudley has already said how pleased we are to see our foreign guests, and we have with us gentlemen from Sweden, from France, from America, from Germany and other countries. It is quite impossible for me to mention all their names, and I must ask you to take them *en bloc*. I do want to refer, however, to the presence of Lord May. (*Applause.*) I think that Lord May now loves us very much more than he did at first, and the more he gets to know us the more he will love us. (*Laughter.*) We also greatly appreciate here the presence of Sir Andrew Duncan, who manages our affairs with extreme courtesy and good temper, and he has had very difficult times of late. (*Applause.*)

I must add a word in conclusion about the Press. When I was young there was only one paper which was devoted to the iron and steel trade, and that was a very small one with a very small circulation. To-day the position has changed, and we have now a dozen papers which are well informed and do tell the public that we are not out-of-date, as so many of them have been inclined to think. We welcome the representatives of the Press to our banquets, and we also welcome them to our works. We also welcome the Press for introducing a brighter element into our monotonous conversation in our works. Let me read you something which appeared in the *Daily Express* last week : " And has modern mind evolved anything more grotesque and frightening than blast-furnaces? They tower up like bloated gas-masks, hideous and black as Gustave Doré drew hellish buildings for Dante's 'Inferno'." (*Loud laughter.*) *The Times*, referring to Dorman Long's works, spoke of " the golden lava flowing from the mammoth furnace along sinuous runnels to beds of sand, producing the effect of a sunset in the Sahara " (*laughter*), and it also was, I think, in *The Times* that reference was made to " the fiery ingot travelling on the mysterious runnels to the jaws of the rollers, as eagerly as a maiden to the trysting place." (*Laughter.*)

The rôle of guests is not always a happy one. In the past it was apt to be dangerous. I have with me a little book called " Cautionary Maxims for Guests." (*Laughter.*) Among other things, it warns you not to dine with the customer when you are going to make a bargain, and it also mentions many historic instances of dangers to guests. It refers to Procrustes. Procrustes invited travellers to his castle, and after dinner put them to bed; if the bed was too long he cut off the ends of their legs, and if it was too short he stretched them until they fitted it exactly. My little book also mentions the case of Jael and Sisera. Sisera was invited into her tent by Jael, and when he lay down to sleep she took a hammer and a nail and

smote the nail through his temple to the ground, and he died. My little book says that this is a bad thing, and it was a bad thing. (*Laughter.*) But Deborah sang a song "Blessed above women shall Jael the wife of Heber the Kenite be; blessed shall she be above women in the tent. He asked water, and she gave him milk; she brought forth butter in a lordly dish. She put her hand to the nail, and her right hand to the workman's hammer; and with the hammer she smote Sisera, she smote off his head, when she had pierced and stricken through his temples. At her feet he bowed, he fell, he lay down; at her feet he bowed, he fell; where he bowed, there he fell down dead." My little book also contains one or two medical maxims, including the advice that if "yo doe ate bitter almonds before yo fall into drinking company it will cause yo to be overcome less than most." (*Laughter.*) I mention that for the benefit of the younger people; the older ones have probably some prescription of their own. (*Laughter.*)

I hope that our guests have had a very pleasant evening and have enjoyed our company as much as we have enjoyed theirs. I have great pleasure in proposing this toast, and coupling it with the name of His Excellency the Belgium Ambassador. (*Applause.*)

His Excellency Baron de Cartier de Marchienne, G.C.V.O., Belgian Ambassador Extraordinary and Plenipotentiary to the Court of Saint James, who responded, said: After the very delightful and the very amusing speeches which we have heard to-night from Lord Willingdon, the Chairman, Sir Thomas Inskip and Mr. Lysaght, I feel nonplussed. However, I will try to do my best, because I have to speak in the name of the guests. When I heard the names of the guests enumerated, it sounded to me like a litany, and a litany of the saints. (*Laughter.*)

Mr. Lysaght has referred to my name, and I sometimes derive some consolation from the thought that a very celebrated firm of jewellers also has the same name, and when I have the honour to be introduced to ladies they invariably catch my name and ask me whether I am a member of the firm. (*Laughter.*) I regretfully have to confess that I am not, and I say "regretfully" because I would much rather be a member of the firm of Cartier than the Belgian Ambassador. (*Laughter.*)

That I have been asked to respond to this toast is due to a very kindly thought on the part of my friend Lord Dudley. He comes from a long line of ironmasters, and I am proud of the fact that I too come from a long line of ironmasters—I nearly said ironmongers (*laughter*)—my grandfather was one of the founders of a famous Belgian steel company of some reputation in our country. When I have come back from some foreign country, from Japan or Denmark or wherever it may be, and I see the chimney stacks smoking again, my heart warms up and I feel that at last I am home again.

The hour is late, and we have had such excellent speeches that I

should not like to spoil the effect by continuing. (*Laughter.*) We have had the climax, and now I have provided the anticlimax, so that I will conclude by thanking you for the very delightful evening which your guests have had. If you think of asking us again next year, we shall be glad to come. (*Laughter and applause.*)

Mr. ALFRED HUTCHINSON, M.A., Past-President then proposed the toast of

The President.

He said: It is with very great pleasure that I rise to propose the toast of our Chairman. Our greatest national poet has said that some men are born to greatness and some have greatness thrust upon them. Our Chairman clearly belongs to the former class. He comes of a great family, and he served his country in the Great War, in which he earned the Military Cross. His parliamentary services have been of great benefit to the nation; beginning with his membership of the House of Commons, on succeeding to the earldom he went to the House of Lords, and has thus given national service in both Houses of Parliament. As an hereditary peer he has upheld the dignity of the House of Lords, and he has taken an active part in the parliamentary control of our great Empire. It is more especially for his services to the steel trade, however, that I ask you to drink his health this evening. His own company holds an important position in the steel trade, and he has personally rendered yeomen service to the trade, having been President of the British Iron and Steel Federation some two years ago. (*Applause.*)

To Lord Dudley our own Institute owes special thanks in that he consented at the request of the Council to act as President during the year in which the Institute is to visit America. We hope that under his guidance and chairmanship our Members will have an extremely successful and pleasant visit, which will result in further cementing the friendship which already exists between members of the English iron and steel industry and those in the United States, a friendship which can do so much to foster and improve international trade relations. (*Applause.*)

With regard to research and technical developments, for which this Institute more particularly stands, I would remind you that Lord Dudley's family has for many generations taken an active part in the technical developments of the trade. Dud Dudley, Lord Dudley's forebear, was primarily responsible for the development of the use of coal instead of charcoal in the production of pig iron in the blast-furnace, and published his claims as long ago as 1665. As so often happens, the course of development was a thorny one and he had great difficulty in obtaining his patent. He was twenty years of age when he left the University of Oxford to manage his father's works near Dudley, and it was there that in 1665 he succeeded in making pig iron by the use of coal in a blast-furnace. This enabled

him to use increasing quantities of coal from the Dudley estate, thereby providing additional employment in the district. In the days when wrought iron reigned supreme, as many as sixty-six puddling furnaces were in operation at the Dudley works, and when steel began to replace iron they at once determined to adopt the new process. Lord Dudley himself has been responsible for the reconstruction and modernisation of the whole works.

It will be evident, therefore, that our President has inherited a flair for research and technical development in the trade, and he provides a striking example of how men in high positions, with other great national responsibilities, have devoted themselves to the steel industry, which is such a national asset and which in times of difficulty and danger will prove of inestimable value to the nation. We are glad, therefore, to have Lord Dudley as our President, and we wish him a most successful year of office. (*Applause.*)

The PRESIDENT, who was received with applause on rising to respond, said : Mr. Hutchinson, in his usual charming way, and as would be expected of a very old friend, has made out an excellent case from very slender material. (*Laughter.*) You have received his words with great cordiality, but I am still not persuaded that I am a suitable President for your great Institute, any more than I expect that you are so persuaded. (*Laughter.*) I feel in my own heart that the main qualification for the Presidency of this Institute is to be an expert in steelmaking—one who has been through the technical mill and has years of scientific experience behind him. I cannot make that claim for myself, though Mr. Hutchinson can make it for himself. However, you have done me the honour of electing me to this high office at a comparatively early age, and my doctor assures me that I have many years ahead of me. I can only tell you, therefore, that I will do my best in spite of my deficiencies, and, in the years to come, strive to promote your interests to the greatest advantage. I cannot say more than that, and I say that from my heart. I thank you for your kindness to me this evening, and once again assure you of my whole-hearted determination to do everything I can to fulfil worthily the high and honourable trust which you have placed upon my shoulders. (*Applause.*)

FRIDAY MORNING, MAY 6, 1938.

The Meeting was resumed on this morning at 10 A.M.; the President (Lord Dudley) occupied the Chair.

Andrew Carnegie Research Scholarships.

The SECRETARY announced that Andrew Carnegie Research Scholarships had been awarded to the following :

G. E. A. BRAMLEY (The University, Sheffield) : £100 in aid of a research on the determination of oxygen in steel.

P. T. CARTER (Armstrong College, Newcastle-on-Tyne): £100 in aid of an investigation on the Properties of graphite.

R. GRIFFITHS (University College, Swansea): £100 in aid of a research on the oxidation of steel.

(The above researches are being carried out on behalf of the Research Committees of the Institute.)

O. GESSNER (Breslau, Germany): £100 in aid of investigations on the "internal friction" of cast-iron alloys, steel, metals and alloys and slags.

B. KNAPP (Berlin, Germany): £100 in aid of a research on the mechanism of the reaction of carbon with hydrogen in steel.

A. B. WINTERBOTTOM (Trondheim, Norway): £100 in aid of an investigation of the formation and growth of oxide films on metals by polarimetric methods.

The Secretary also announced that it had been decided that no award of the Andrew Carnegie Gold Medal should be made for the year 1937.

Death of the Duke of Devonshire.

Dr. C. H. DESCH F.R.S. (Vice-President), who was in the Chair in the temporary absence of the President (Lord Dudley), said that news had just been received of the death of the Duke of Devonshire. His Grace had joined the Institute in 1894; he had been President from 1910 to 1912, and took a very active part in the Buxton Meeting of 1910. In many ways he had rendered great services to the Institute.

The members stood in silence for a few moments as a token of respect.

Presentation of Papers.

The following Report and papers were presented for discussion:

"THE APPLICATION OF TIME STUDY TO ROLLING MILLS," by the Rolling Mill Committee of the Iron and Steel Industrial Research Council (*Special Report No.* 20).

C. A. EDWARDS, F.R.S., D. LUTHER PHILLIPS and D. F. G. THOMAS: "Influence of Composition and Treatment on Rate of Acid Attack on Mild Steel."

B. JONES and N. GRAY: "Martensitic Grains in Rapidly-Cooled Ingot Iron and Mild Steel."

The Meeting then adjourned for lunch.

FRIDAY AFTERNOON.

The Meeting was resumed at 2.30 P.M.; the President (Lord Dudley) occupied the Chair.

Presentation of Papers.

The following papers were then presented:

W. A. BONE, F.R.S., H. L. SAUNDERS and H. J. TRESS: "An Experimental Enquiry into the Interactions of Gases and Ore in the Blast-

Complete List of the Reports and Papers Presented at the Annual General Meeting, 1938.

"THE APPLICATION OF TIME STUDY TO ROLLING MILLS." By the Rolling Mill Committee of the Iron and Steel Industrial Research Council (*Special Report No.* 20).

"THE FIFTH REPORT OF THE CORROSION COMMITTEE." By a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation (*Special Report No.* 21).

C. R. AUSTIN and H. D. NICKOL: "Comparison of the Tensile Deformation Characteristics of Alloys at Elevated Temperatures."

W. A. BONE, F.R.S., H. L. SAUNDERS and H. J. TRESS: "An Experimental Enquiry into the Interactions of Gases and Ore in the Blast-Furnace. Part V.—The Influences of Hydrogen and Steam at 450–850° C."

C. A. EDWARDS, F.R.S., D. LUTHER PHILLIPS and D. F. G. THOMAS: "Influence of Composition and Treatment on the Rate of Acid Attack on Mild Steel."

R. HARRISON: "The Effect of Copper on some Alloy Steels."

B. JONES and N. GRAY: "Martensitic Grains in Rapidly-Cooled Ingot Iron and Mild Steel."

J. A. JONES and W. C. HESELWOOD: "The Effect of Chromium and Carbon Contents on the Coefficients of Thermal Expansion of Chromium Steels."

B. MATUSCHKA: "Solidification in Open-Topped and Closed-Topped Ingot Moulds."

E MAURER and F. HADERER: "The Exact Quantitative Estimation of Ferric Oxide and Sulphide Sulphur in Basic Slags."

C. E. RICHARDS: "The Atmospheric Corrosion of Galvanised Iron Wire and its Bearing on Specification Testing."

Communication:

"Note on Brittle Nickel Steel," by the late Dr. J. E. STEAD, F.R.S.

Furnace. Part V.—The Influences of Hydrogen and Steam at 450–850° C."

C. E. RICHARDS : "The Atmospheric Corrosion of Galvanised Iron Wire and Its Bearing on Specification Testing."

"The Fifth Report of the Corrosion Committee" (*Special Report No.* 21) was formally presented, but time did not permit for its discussion.

THE PRESIDENT (Lord Dudley), in bringing the Meeting to a conclusion, said that there would be general agreement that it had been a highly successful one. It had been very well attended; some most interesting papers had been read by a variety of speakers, and the discussions to which they had given rise had been of great interest and value. It had been unfortunate that so far as he was concerned the Meeting had clashed with a number of appointments which he could not avoid; the result had been that he had had to leave the Chair on several occasions, and for that he offered his apologies. He wished to thank Mr. Hutchinson and Dr. Desch, who had presided in his absence. He had enjoyed being present and had been most interested in the discussions.

Vote of Thanks to the President

Sir HAROLD CARPENTER, F.R.S. (Past-President), moved a hearty vote of thanks to Lord Dudley for his conduct in the Chair. The Members were glad to hear Lord Dudley say that he had enjoyed his experience. The meeting had been an unusually long one, owing to the fact that two days had been devoted to the Symposium on Steelmaking. There was, he thought, no doubt that it was a very wise decision on the part of the Council to allow that extra time; the quality of the papers presented and of the discussion, as the President had pointed out, had been so good that the Council would feel that they had come to a wise decision in making provision for the Symposium to be held.

He would like to offer Lord Dudley special congratulations on the brilliant success of the Dinner the previous evening; Lord Dudley had presided over the largest Dinner in the history of the Institute, and all those who attended had been very much impressed with the high quality of the speeches and the pleasant character of the proceedings generally. They felt that Lord Dudley had achieved a great success on that occasion.

As Lord Dudley had pointed out, other duties had not permitted him to be present for the whole time of the Meeting, and therefore he would ask permission to include in the vote of thanks Mr. Alfred Hutchinson and Dr. C. H. Desch, who had occupied the chair when Lord Dudley was unable to be present.

The vote of thanks was carried with acclamation.

The PRESIDENT, in thanking the Meeting for the cordial way in which they had received Sir Harold's remarks, again expressed his own thanks to Mr. Hutchinson and to Dr. Desch for having acted as *locum tenens* on so many occasions. He was proud that the Institute had had such a successful Annual Meeting and Dinner during his year of office.

Vote of Thanks to the Institution of Civil Engineers.

The PRESIDENT (Lord Dudley) said that he knew it would be the wish of the Members that they should not conclude the proceedings without passing a very hearty vote of thanks to their good friends, The Institution of Civil Engineers, for lending them their premises once more and for placing their Lecture Theatre at the disposal of the Institute for the purposes of the Meeting.

The vote of thanks was carried with acclamation and the proceedings then terminated.

REPORT OF COUNCIL.

THE Annual Report of the proceedings and work of the Iron and Steel Institute during the year 1937 is submitted by the Council for the approval of Members at this, the Sixty-Ninth Annual General Meeting. For the convenience of Members some sections of this Report include information up to March 31, 1938.

ROLL OF THE INSTITUTE.

The membership of the Institute has again increased, and with a total of two thousand four hundred and eighty-seven at December 31, 1937, was greater by two hundred and forty-four than at the beginning of the year. Neither figure has previously been exceeded.

The details of the membership compared with those of a year ago are as follows :

	31/12/'36.	31/12/'37.
Patron	1	1
Honorary Members	15	15
Life Members	67	66
Ordinary Members	2042	2224
Associates	118	181
	2243	2487

Included in both totals are seven Members whose names are retained on the Register in an honorary capacity by order of the Council.

Variations in the membership since the foundation of the Institute in 1869 are shown in Fig. 1.

During the year forty-four Members and six Associates resigned and the deaths of thirty-six members were reported. Nine Associates were transferred to membership and seven former Members were reinstated.

The new elections consist of two hundred and fifty-nine Members and seventy-nine Associates; these include eighty-four Members and twenty-three Associates nominated by Companies under the provisions of the Special Subscription Fund, and one hundred and eight Members and twenty-eight Associates who joined under the scheme of co-operation with the Institute of Metals; fifteen Associates were elected under the special arrangements made with the American Institute of Mining and Metallurgical Engineers.

The increase in membership must be considered satisfactory, but it is largely due to the election of members of the Institute of Metals

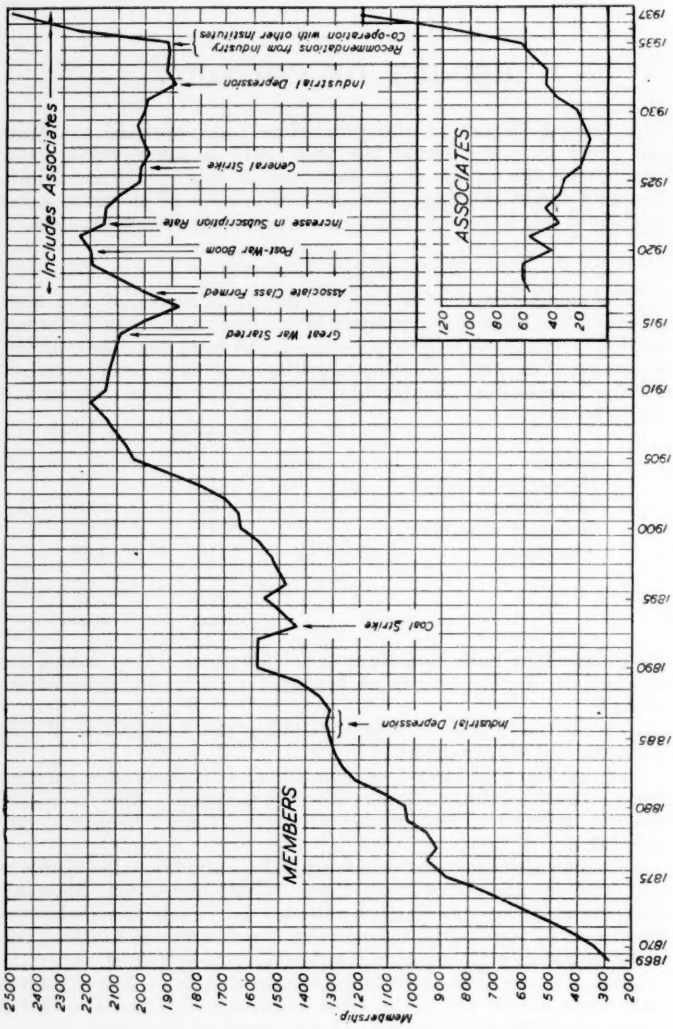
MEMBERS
ASSOCIATES
Membership.
Includes Associates
Industrial Depression
Coal Strike
Great War Started
Associate Class Formed
Post-War Boom
Increase in Subscription Rate
General Strike
Industrial Depression
Recommendations from Industry
Co-operation with other Institutes
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
120
100
80
60
40
20
1869
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1937

FIG. 1.

and so large an increase in membership from this source cannot be expected to recur. The Council are gratified by the number of new Members nominated by Companies which subscribe to the Special Subscription Fund. According to the arrangements which have now been in force for two years, subscribers to this Fund are entitled to nominate Members of their staffs, who are qualified to join the Institute, and to set the amount of their entrance fees and first year's subscription (but not those for subsequent years) against the amount subscribed to the Fund. At the end of the first year Members and Associates nominated in this way become personally liable for their subscriptions, but Companies are entitled to nominate additional members of their staffs to join the Institute as long as they continue to subscribe to the Fund.

The Council hope that subscribers to this Fund will continue to avail themselves of these facilities. In their opinion the potential membership of the Institute is substantially greater than that which has yet been attained, and they hope that with the constant expansion of the services rendered to Members, membership of the Institute will appeal to a greater proportion of those who are engaged in the iron and steel industry or who are interested in ferrous metallurgy.

The increase in the number of Associates from one hundred and eighteen to one hundred and eighty-one is satisfactory, but the Council hope that in the future the Institute may prove of value to a far greater number of junior research workers and to the younger members of the industry.

Obituary.

The Council regret to record the deaths of the following twenty-seven members of the Institute which occurred during the year 1937:

Ajuria y Urigoitia, Serafin (Vitoria, Spain)	March 3.
Aspinall, Sir John A. F. (Woking, Surrey)	January 18.
Bond, H. C. (Wargrave Court, Berkshire) (Hon. Vice-President)	June 12.
Bull, Major R. A. (Chicago, Ill., U.S.A.)	July 29.
Chantry, F. (Sheffield)	?
Clark, W. (Skelmorlie, Ayrshire)	March 13.
Couves, H. A. (Newcastle-upon-Tyne)	March 25.
Cross, W. (London)	October 16.
Davy, W. J. (Bowdon, Cheshire)	?
Delprat, G. D., C.B.E. (Melbourne, Australia)	March 15.
Dewrance, Sir John, G.B.E. (Thetford, Norfolk)	October 7.
Elias y Suarez, Pedro (Baracaldo, Spain)	?
Hafels, E. W. (London)	September 4.
Johnson, H. B. (Chester)	July 5.
Langenburg, F. C. (Burlington, N.J.)	April 4.

Leach, G. C. (London)	April 6.
McBean, Colonel A. (Wolverhampton)	February 16.
Macnab, T. P. (London)	?
Masaryk, Dr. T. G. (Prague, Czechoslovakia) (Hon. Member)	September 14.
Pollen, A. J. H. (London)	January 28.
Reichwald, V. B. (London)	November 24.
Richards, D. (Ammanford, Carmarthenshire)	?
Sahlin, A. (London)	June 10.
Sen, P. K. (Calcutta, India)	?
Taverner, G. B. R. (London)	?
Thom, G. (Motherwell)	?
Willis, T. W. (Sheffield)	September 10.

The deaths of the following nine members took place prior to 1937, but had not been previously recorded :

Ball, E. J. (Bristol)	1933.
Bates, W. R. (Wellingborough)	December 15, 1936.
Campbell, Professor Wm. (New York, N.Y., U.S.A.)	December 16, 1936.
Deladrière, L. (Brussels, Belgium)	October 16, 1936.
Dupré, F. (London)	December 9, 1936.
Osborn, I. S. (Sheffield)	December 19, 1936.
Lindman, Admiral Arvid (Stockholm, Sweden)	December 9, 1936.
Sargent, Dr. G. W. (Pittsburgh, Pa., U.S.A.)	May, 1936.
Slater, W. F. (Shotton)	November 19, 1936.

The Council desire to place on record their sincere regret at the death of His Excellency Dr. T. G. Masaryk, the Liberator and former President of Czechoslovakia, an Honorary Member of the Institute. His Excellency Admiral Arvid Lindman, besides holding high rank in the Swedish Navy, had been a distinguished member of the Government of that country, and had twice been Prime Minister. Mr. A. Sahlin had been a strong supporter of the Institute and had contributed papers to the *Journal*; he was one of the founders of the International Construction Co., Ltd., and had been connected with the construction and operation of iron and steel manufacturing plant in every important producing country in Europe, in the United States of America and India. Mr. H. C. Bond, a Member of Council since 1929, and an Honorary Vice-President since 1936, had been associated for over fifty years with Messrs. Richard Thomas & Co., Ltd., and was widely known in the tinplate industry of South Wales. Sir John Dewrance, Chairman of Babcock & Wilcox, Ltd., and of John Dewrance & Co., had for many years been on the General Board of the National Physical Laboratory; he had been Chairman of the

British Cast Iron Research Association and a Member of the Engineering Research Board and of the Commerce Degrees Committee of the University of London as well as President of the Institution of Mechanical Engineers and of the Institute of Metals. Sir John Aspinall had been intimately connected with the evolution of the present railway system in Great Britain; he was a Past-President of the Institution of Civil Engineers, of the Institution of Mechanical Engineers, of the Institution of Civil Engineers of Ireland, and of the Junior Institution of Engineers; he was one of the oldest members of the Iron and Steel Institute, having been elected in 1887. Professor William Campbell was one of the foremost authorities on metallurgy in the United States of America, while Major Bull was an outstanding steel-foundry metallurgist of that country. Colonel McBean's name was noted for its long association with the iron and steel trade of the Midlands; he was also a strong supporter of the Institute, and had been elected to membership in 1894.

It is with deep regret that the Council have heard of the sudden deaths of several Spanish Members during this and the previous year; they include those of several Members who were prominently connected with the hospitality extended to the Institute in 1928.

Finance.

The accounts for the year ending December 31, 1937, resemble those for the previous year except for differences attributable to the increase in the activities of the Institute and the increase in membership.

General Fund.—Income and Expenditure Account.

The ordinary income of the General Fund at £12,661 was £1689 higher than the comparable figure for the previous year. This was mainly caused by an increase of £1000 in the grants received from the Iron and Steel Industrial Research Council. There was a welcome increase in the amount received from subscriptions (£370), which reflects the increased membership—the full benefit of this will not be apparent until later years—and a satisfactory increase in the receipts for sales of publications which, after including sales of the volumes of the Welding Symposium, realised £300 more than during the previous year.

The ordinary expenditure of the General Fund at £14,525 was £1669 higher than the comparable figure for the previous year. Staff expenses have increased by £231, but expenses on the office, including rent, decorations and furniture, have been reduced by approximately the same amount (£203). Expenses on Meetings—always a widely fluctuating figure—have more than doubled, being £693 as against £314. Publishing expenses have increased by £614; not only have members received more in return for their subscriptions but the increased membership has necessitated the printing of bigger editions of all publications.

According to new arrangements made with the Iron and Steel Industrial Research Council, the grant to that organisation has been fixed at £2500, a sum which the Council consider to be commensurate with the Institute's interest in research. The Institute has continued to take an active part in the joint research activities of the industry and this is reflected in the accounts, not only by the increase of £1000 in this grant but also by the increased grants received from the Research Council, to which reference has been made. In the course of this work the Institute has administered substantially greater sums at the request of the Research Council, but these do not affect the finances of the Institute and must, therefore, be excluded from these accounts.

Other grants to research organisations totalled £200 and were £25 less than during the previous year. There has been an increase of £139 in the total of the remaining items of expenditure. During the previous year an item of £614 was charged as final expenditure (less receipts during the year) incurred on the Symposium on the Welding of Iron and Steel which was held in May, 1935, and all financial liability on the account was thus terminated. As mentioned above, receipts (of £149) have been obtained from the sale of proceedings during the year now under consideration.

The ordinary expenditure of the General Fund exceeded the ordinary income by £1864, or £20 less than in the previous year.

The receipts of the Special Subscription Fund have as usual been taken into account, the amount received being £3001 in place of £3306 ; after transfer to reserve accounts (£226 as against £449) and subscription accounts (£283 as against £669) in the usual way, the sum of £628 in place of £224 was available to carry to the balance sheet as excess of income over expenditure for the year.

General Fund.—Balance Sheet.

The balance sheet calls for little special comment, being closely comparable to those for previous years. The value of the Institute's investments has been well maintained, the market value at December 31, 1937, at £28,307 comparing satisfactorily with the exceptionally high figure of £28,512 a year before. The cost price at which they are valued in the balance sheet has increased from £23,874 to £24,896 owing to new purchases which were made during the year.

Special Subscription Fund.

The Council wish again to express their grateful thanks to the Companies and Associations which have contributed to the Special Subscription Fund, and to those individuals who have personally interested themselves in the payment of these subscriptions.

The total received during the year was, as mentioned above, £3001 10*s.* 0*d.*, being a reduction of approximately 10% on the figure of £3306 received during the previous year. The Council hope

that subscriptions will be maintained, so that an income of not less than £3000 a year may be assured, since it is apparent that without these subscriptions the work of the Institute cannot be maintained at its present level, nor can developments be undertaken in the future. The Council have been giving careful consideration to this subject as well as to the possibility of placing this source of income on a more permanent basis.

The following are the present subscribers to the Fund :

C. Akrill & Co., Ltd.
Edgar Allen & Co., Ltd.
Andrews Toledo, Ltd.
John Bagnall & Sons, Ltd.
John Baker & Bessemer, Ltd.
Baldwins, Ltd.
Arthur Balfour & Co., Ltd.
Bayliss, Jones & Bayliss, Ltd.
Birchley Rolling Mills Co., Ltd.
Frederick Braby & Co., Ltd.
Bradley & Foster, Ltd.
John Bradley & Co. (Stourbridge), Ltd.
The Brightside Foundry & Engineering Co., Ltd.
Briton Ferry Steel Co., Ltd.
Broken Hill Proprietary Co., Ltd.
Burnell & Co., Ltd.
Bynea Steel Works, Ltd.
Clay Cross Co., Ltd.
Colvilles Ltd. (including Clyde Alloy Steel Co., Ltd., Lanarkshire Steel Co., Ltd., and the Steel Company of Scotland).
Consett Iron Co., Ltd.
Darwen & Mostyn Iron Co., Ltd.
Davy & United Engineering Co., Ltd.
Dorman Long & Co., Ltd.
Thos. Firth & John Brown, Ltd.
W. T. Flather, Ltd.
General Refractories, Ltd.
Josiah Guest & Sons, Ltd.
Guest Keen Baldwins Iron & Steel Co., Ltd.
Guest Keen & Nettlefolds, Ltd.
J. J. Habershon & Sons, Ltd.
Hadfields, Ltd.
Harts Hill Iron Co., Ltd.
N. Hingley & Sons, Ltd.
Wm. Jessop & Sons, Ltd.
Kayser Ellison & Co., Ltd.
Lancashire Steel Corporation, Ltd.
Arthur Lee & Sons, Ltd.
Llanelly Steel Co. (1937), Ltd.
John Lysaght, Ltd.

Neepsend Steel & Tool Corporation, Ltd.
Newton Chambers & Co., Ltd.
Old Castle Iron & Tin-Plate Co., Ltd.
Oughtibridge Silica Firebrick Co., Ltd.
Samuel Osborn & Co., Ltd.
Park Gate Iron & Steel Co., Ltd.
Partridge Jones & John Paton, Ltd.
Thomas Perry & Son, Ltd.
Roll Makers Association.
Round Oak Steel Works, Ltd.
Sheepbridge Coal & Iron Co., Ltd.
Sheet Makers' Conference.
Simon-Carves, Ltd.
F. R. Simpson & Co., Ltd.
South Durham Steel & Iron Co., Ltd., and Cargo Fleet Iron Co., Ltd.
South Wales Siemens Steel Association.
Spear & Jackson, Ltd.
Stanton Ironworks Co., Ltd.
Staveley Coal & Iron Co., Ltd.
Stewarts & Lloyds, Ltd.
John Summers & Sons, Ltd.
Tata, Ltd.
Taylor & Farley, Ltd.
Richard Thomas & Co., Ltd.
United Steel Companies, Ltd.
Upper Forest & Worcester Steel & Tinplate Works, Ltd.
Vickers, Ltd.
T. W. Ward, Ltd.
Welsh Plate & Sheet Manufacturers' Association.
Whitehead Iron & Steel Co., Ltd.

Andrew Carnegie Research Fund.

The income of the Andrew Carnegie Research Fund for the year at £1153 was almost the same, and the expenditure at £1155 was £163 less, than for the previous year. The excess of expenditure over income carried to the Balance Sheet was £1 16*s.* 10*d.* compared with £166 14*s.* 2*d.* a year ago.

Research grants paid during the year amounted to £775 as against £1075 during the previous year, the net cost to the Fund being £575, a figure which is £250 less than a year ago. The Balance Sheet requires no special comment, except that the market value of the investments at December 31, 1937, was £31,455, compared with £32,695 at December 31, 1936, and the cost price of £25,356 at which they are taken into account.

Williams Prize Fund.

No award having been made during the year, the income from

the Fund, amounting to £108, has been carried to the Balance Sheet. The Council are pleased that since the close of the year this Prize has been awarded for the first time for three years.

Bessemer Gold Medal.

Two Bessemer Gold Medals were presented in 1937, one to Colonel N. T. Belaiew, C.B., in recognition of his fundamental researches extending over twenty-five years on the crystallisation of metals, particularly steel, and the other to Monsieur Aloyse Meyer, whose distinguished career has been devoted to the technical and industrial progress of the iron and steel industry.

The Council have decided to award the Bessemer Gold Medal for 1938 to Dr. C. H. Desch, F.R.S.

Changes on the Council.

Mr. Alfred Hutchinson, M.A., was inducted as President at the Annual General Meeting on April 29, 1937.

As announced at that Meeting, Dr. Fritz Springorum and Dr. Ernst Poensgen were nominated Honorary Vice-Presidents and Dr. Otto Petersen an Honorary Member of the Institute.

During the year Sir Frederick Mills, Bt., D.L., M.P. (Past-President) was also nominated an Honorary Member. The Hon. Roland D. Kitson, D.S.O., was made an Honorary Vice-President and Mr. A. O. Peech was elected a Vice-President. Professor Léon Guillet accepted the Council's invitation to become an Honorary Vice-President, and Dr. C. A. Edwards, F.R.S., and Mr. J. R. Menzies Wilson were elected Members of Council. Mr. P. M. Ritchie became an Honorary Member of Council on succeeding Dr. A. McCance as President of the West of Scotland Iron and Steel Institute.

Since the end of the year Mr. T. B. Smith has succeeded Mr. W. F. Bowden as President of the Cleveland Institution of Engineers, and as an Honorary Member of the Council.

In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced as being due to retire at the Annual Meeting in 1938 :

Vice-Presidents : Dr. C. H. Desch, F.R.S.; Mr. Arthur Dorman; Mr. H. Spence Thomas.

Members of Council : Dr. T. Swinden, Dr. A. McCance; Mr. P. B. Brown; Mr. A. O. Peech; Captain H. Leighton Davies.

Mr. A. O. Peech having been elected a Vice-President, Mr. I. F. L. Elliot becomes due to retire in his stead.

No other Members having been nominated up to one month previous to the Annual Meeting, the retiring Members are presented for re-election.

Honours Conferred on Members.

The Council offer their hearty congratulations to Members of the Institute on honours and appointments received during 1937.

Sir Harry McGowan has been created a baron with the title of Baron McGowan of Ardeer. On the death of his brother, Sir Francis Samuelson became a baronet. Colonel K. C. Appleyard's name was included in the Coronation Honours List as a recipient of the O.B.E. Sir Robert Hadfield, Bt., D.Sc., D.Met., F.R.S., was raised to the distinction of a Commander of the Legion of Honour, while the Order of Chevalier of the Legion was conferred on Mr. B. Clasen and Mr. I. F. L. Elliot. Mr. N. Parravano was appointed Pontifical Academician by the Pope. Professor K. Honda was invested with the newly created Imperial Order of Culture on the occasion of the birthday, on April 29, of His Imperial Majesty the Emperor of Japan; the order is conferred on those who have made outstanding contributions to the progress of science and the fine arts. Engineer Vice-Admiral Sir Harold Brown has been appointed Master General of Ordnance; he will retain his post as Director General of Munitions Production. Lieutenant Colonel A. S. W. Dore, D.S.O., has been appointed Deputy-Lieutenant of the County of Middlesex; he has also been elected Vice-Chairman of the Middlesex Territorial and Air Force Association. Mr. H. A. Davies has received the Freedom of the Borough of Wednesbury, while Mr. James Tennent has been appointed a Provost of the Burgh of Coatbridge, and Mr. E. W. Senior and Mr. W. W. Wood have been made Justices of the Peace for the City of Sheffield.

At their General Meeting in Düsseldorf on October 10, 1937, the Verein deutscher Eisenhüttenleute conferred signal honours on two prominent Members of the Iron and Steel Institute; the Carl Lueg Gold Medal was awarded to Sir Harold Carpenter, F.R.S., while Mr. James Henderson was elected an Honorary Member of the Verein.

Dr. W. Hume-Rothery has been elected a Fellow of the Royal Society; Dr. J. H. W. Laverick has been appointed Chairman of Convocation of the University of Sheffield. Sir Robert Hadfield, Bt., D.Sc., D.Met., F.R.S., has been elected an Honorary Member of the Institution of Civil Engineers; Sir Robert Mond, M.A., LL.D., has been elected an Associate Member of the Académie des Inscriptions et Belles Lettres. Dr. S. F. Dorey has received a Telford Premium from the Institution of Civil Engineers, while Professor C. Benedicks has been awarded the Henri Becquerel Foundation for Scientific Research by the Académie des Sciences. Dr. P. D. Merica will be the recipient of the John Fritz Gold Medal for 1938, while Professor Thomas Turner is the first to receive the E. J. Fox Gold Medal awarded by the Institute of British Foundrymen. Dr. C. C. Paterson has received the honorary degree of Doctor of Science from the University of Birmingham, while the

degree of Doctor of Metallurgy has been conferred upon Dr. G. B. Waterhouse by Sheffield University. Dr. R. Seligman has received the Diploma of Fellowship of the City and Guilds of London Institute. The Senate of Sheffield University have conferred the degree of Doctor of Philosophy on Mr. H. E. Davies. Dr. Harold Moore, C.B.E., has been elected a Fellow of the Institute of Metals, while Mr. E. Wharton has been elected a Fellow of the Institute of Chemistry.

Lord Riverdale has been appointed Chairman and Viscount Falmouth a Member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research. Dr. C. H. Desch, F.R.S., has become President and Professor J. H. Andrew a Vice-President of the Institute of Metals. Professor F. Bacon was President of the South Wales Institute of Engineers, and Professor G. B. Waterhouse President of the American Society for Metals; Mr. J. B. Allan is President of the Sheffield and District Section of the Institute of British Foundrymen. Mr. L. Chapman has been re-elected President of the Crucible Steel Makers' Association, and Mr. E. J. Fox has been elected the first Chairman of the Foundry Pig Iron Producers' Association. Mr. J. H. G. Monypenny is the Chairman of the British Chemical Plant Manufacturers' Association. Mr. A. J. Grant has been elected Senior Warden and Mr. A. S. Ward Junior Warden of the Cutlers' Company in Hallamshire; Mr. J. G. Pearce has been elected to the Freedom and Livery of the Worshipful Company of Founders. The Earl of Dudley, M.C., Mr. A. J. Grant and Mr. Arthur Dorman are Presidents of the Birmingham, Sheffield and Tees-Side Chambers of Commerce, respectively. Mr. P. Baxter has been appointed to represent the Scottish Steelmakers' Association on the directorate of the Glasgow Chamber of Commerce (in place of Mr. John Lennox), while Mr. L. Chapman has been elected to fill the vacancy on the British side of the Russo-British Chamber of Commerce Executive Council.

Meetings.

The Annual General Meeting of the Institute was held on Thursday and Friday, April 29 and 30, 1937; Sir Harold Carpenter, F.R.S., the retiring President, was in the Chair, and was followed by Mr. Alfred Hutchinson, M.A., B.Sc.

The Annual Dinner took place at Grosvenor House, Park Lane, London, W.1., on Thursday, April 29, 1937.

The Autumn Meeting was held in Middlesbrough from Tuesday to Friday, September 14 to 17, 1937, at the cordial invitation of the Iron, Steel and Engineering Industries of Middlesbrough and the Cleveland District. Two sessions for the discussion of papers were held on the mornings of September 15 and 16 in the Cleveland Scientific and Technical Institute, and the afternoons of those days and the whole of Friday were devoted to visits to a large number

of steelworks in the neighbourhood which were kindly thrown open to inspection by the visitors. At the same time a programme of excursions had been arranged for the ladies.

On the evening of Tuesday, September 14, the Members and their Ladies were received at the Constantine Technical College by His Worship the Mayor of Middlesbrough (Councillor G. Carter) and the Mayoress on behalf of the Corporation of Middlesbrough. On the 15th the visitors were entertained to lunch in the Town Hall, Middlesbrough, by the invitation of the Mayor of Middlesbrough and the Chairman and Members of the Reception Committee; Mr. A. Dorman presided. In the evening, Sir Maurice Bell, Bt., C.M.G., entertained the Members and their Ladies at an evening party at Mount Grace Priory. In the evening of Thursday, September 16, a ball and supper was given at the Town Hall, Middlesbrough, by the Reception Committee; the President and Mrs. Hutchinson received the guests. On Friday, September 17, after the works visits and Ladies' excursion in the morning, the visitors were conveyed to Solberge Hall, where Mr. Benjamin Talbot, President of the Reception Committee, gave a garden party; the Members and their Ladies were received by Mr. and Mrs. Benjamin Talbot, Miss Talbot and Mr. and Mrs. Chetwynd Talbot. This function brought the Autumn Meeting in Middlesbrough to its close.

Transfer of Offices.

The Council report that they have agreed to rent No. 4, Grosvenor Gardens, Westminster, from December 25, 1937, until September, 1955, and that it is their intention to remove the offices of the Institute to that building not later than June 24, 1938. A part of the building has been sub-let to the Institute of Metals.

The building forms part of the Grosvenor Estate and was formerly in the occupation of the American Embassy. Ample space is available for the present requirements and probable future expansion of the Institute; suitable committee rooms and a large library and reading room will be provided.

Relations With Other Societies and Technical Institutions.

(*For the Period from January* 1, 1937, *to March* 31, 1938.)

The Council are pleased to be able to report the continuance of friendly relations with other Scientific Societies and Technical Institutions.

Co-operation with the Institute of Metals.

The scheme of co-operation with the Institute of Metals, which, as was announced in the last Report, came into force on January 1, 1937, has resulted in an increase in the number of those who are Members or Associates of both Institutes from three hundred and

forty at the beginning of the year to five hundred and twenty-nine at December 31, 1937, a figure which is substantially more than a fifth of the total membership of the Institute. During the year fifty-three members and Associates of the Iron and Steel Institute joined the Institute of Metals and one hundred and thirty-six Members and Student Members of the Institute of Metals joined the Iron and Steel Institute.

According to these arrangements joint membership of the two Institutes can be obtained on payment of a joint subscription at the reduced rate of £5 5*s*. 0*d*. per annum and for a common entrance fee of £2 2*s*. 0*d*., existing Members of one Institute being entitled to join the other without payment of entrance fee if they take up membership within twelve months of election and after that period on payment of an entrance fee of £1 1*s*. 0*d*.

Student Members and Members of the Institute of Metals are accepted as Associates of the Iron and Steel Institute up to the age of thirty and Associates and Members of the Iron and Steel Institute are accepted as Student Members of the Institute of Metals up to the age of twenty-six. The subscription of Associates and Student Members is £1 1*s*. 0*d*. to each Institute without entrance fee or transfer fee on taking up full membership.

The success of these arrangements encouraged the Councils to investigate the possibilities of closer co-operation in other directions. An agreement was reached on December 30, 1937, and has since been approved by both Councils, in accordance with the terms of which the Iron and Steel Institute will sub-let accommodation in No. 4, Grosvenor Gardens to the Institute of Metals so that the offices of both Institutes will be in the same building. The Iron and Steel Institute have undertaken to provide the usual services. In addition, the Libraries of the two Institutes will be joined, the common Library to be under the control of the Iron and Steel Institute with a joint Advisory Committee; the Institute of Metals will subscribe towards the upkeep of the Library and this will be operated impartially in the interest of Members of either Institute.

These provisions will come into force as at June 24, 1938.

The Councils are confident that these arrangements, which provide for closer co-operation in the work of the two Institutes while maintaining their separate identities, are in the best interests of the Members.

Co-operation with Technical Societies Outside Great Britain.

Friendly relations have been maintained with a number of Societies and Technical Institutions outside Great Britain and the special arrangements reported a year ago with the American Institute of Mining and Metallurgical Engineers, L'Association des Ingenieurs Sortis de l'École de Liège and Jernkontoret have been maintained.

In accordance with reciprocal arrangements first inaugurated in 1936, Associates or Members of the Iron and Steel Institute, other

than those residing in America, if under the age of thirty-three, are entitled to become Foreign Student Members of the A.I.M.E. on favourable terms. Since 1936 thirty-eight Members and Student Members of the American Society have joined the Iron and Steel Institute under these arrangements and twenty Members and Associates of the Iron and Steel Institute have joined the A.I.M.E.

By agreement with Jernkontoret, members of the staffs of Companies which are members of Jernkontoret may remain Associates of the Institute up till the age of thirty and Members of the Institute are entitled to purchase *Jernkontorets Annaler* at specially reduced prices. Information can be obtained from the Secretary.

Participation in Meetings and Congresses.

The Institute was invited to take part in a number of Meetings and Congresses and the Council wish to record their appreciation of all invitations received. They were represented at the Centenary Celebrations of l'École des Mines de l'Université de Liège (Faculté Technique et Inauguration des Nouveaux Instituts du Val Benoit) at Liège on November 26 and 27, 1937, by Monsieur Léon Greiner, Honorary Vice-President, and at the General Meeting of the Verein deutscher Eisenhüttenleute at Düsseldorf on October 9 and 10, 1937, by Mr. James Henderson, Honorary Treasurer, and Mr. K. Headlam-Morley, Secretary. On that occasion the Carl Lueg Medal was awarded to Sir Harold Carpenter, F.R.S., and Mr. James Henderson was nominated an Honorary Member. The Carl Lueg Medal has never previously been awarded to a British subject and only once previously has a British subject been made an Honorary Member of the Verein. The Secretary represented the Institute at the Fortieth Anniversary Celebrations of the Foundation of the Association Luxembourgeoise des Ingénieurs et Industriels at Luxemburg on December 4, 1937. Since the close of the year, Mr. Essington Lewis, of the Broken Hill Proprietary Co., Ltd., has represented the Institute at the Annual Engineering Conference of the Institution of Engineers, Australia, at Sydney, New South Wales, during the week commencing March 28, 1938.

The Institute was invited to take part in the following meetings by other Societies :

Electrodepositors' Technical Society.—Papers on "The Tinning of Steel Strip by Electrodeposition." Part I. "Electrodeposition and Polishing of Thin Coatings of Tin on Steel," by Messrs. D. J. Macnaughtan, W. H. Tait and S. Baier. Part II. "The Effect of Deformation on the Protective Value of Hot-Dipped and Electrodeposited Tin Coatings on Steel," by Messrs. D. J. Macnaughtan and J. C. Prytherch.—January 13, 1937.

Institute of Fuel.—Paper by Dr. W. H. Hatfield, F.R.S., on "Heat-Resisting Steels."—March 24, 1938.

The Institute participated in a number of meetings which were organised in conjunction with numerous other societies. These included those organised by :

The Institution of Automobile Engineers.—Discussion on "Research in Relation to the Motor Vehicle."—March 2, 1937; "Essential Conditions Governing the Safety of Modern Road Traffic."—March 1, 1938.

The Institution of Mechanical Engineers.—Discussion on "Lubrication."—October 13–15, 1937.

London Congress of the International Association for Testing Materials.

In conjunction with twenty-nine other Scientific Societies and Technical Institutions in Great Britain, the Institute accepted an invitation to become a Patron Institute of the International Congress of the International Association for Testing Materials which was held in London from April 19 to 24, 1937. Members of the Institute took an active part in the proceedings of the Congress, in the organisation of which the staff of the Institute assisted. The Secretary was Honorary Secretary of the Congress.

Joint Committee on Materials and Their Testing.

The first Meeting to be organised by the Joint Committee on Materials and their Testing was held at Manchester on October 29, 1937, at the invitation of the Manchester Association of Engineers. The subject of discussion was "Notched-Bar Impact Testing," and the following papers were presented :

"Impact Testing from a Physical Standpoint," by Professor R. V. Southwell, M.A., F.R.S.

"Some Aspects of the Notched-Bar Test," by Mr. L. W. Schuster, M.A.

"The Development and Present Position of Continental Research on the Notched-Bar Impact Test," by Dr.Ing. Max Moser.

"Discussion of the Impact Test," by Captain R. K. Haskell and Mr. H. C. Mann.

In addition to the Institute, twenty-four Societies in Great Britain are represented on this Committee. At the first Annual Meeting held in March, 1937, rules were adopted which provide for the limitation of membership to Technical Institutions and Societies agreeing to carry out the objects, such Institutions and Societies to appoint each a representative and to pay an agreed subscription. The terms of reference and objects were defined as follows :

To act as the British national organisation in matters relating to materials and their testing with the following objects, namely :

(1) To promote joint discussions on the wider aspects of those subjects falling within the terms of reference.

(2) To assist a co-operating Institution or Society in the presentation of a paper or group of papers dealing with a more detailed aspect of one of the subjects falling within the terms of reference.

(3) To undertake those duties with respect to international matters which properly devolve on the Joint Committee in accordance with its terms of reference.

The Council believe that the Joint Committee will fulfil a useful function in securing the co-operation of existing Institutions and Societies in the discussion of subjects of common interest relating to materials and their testing and in securing proper British representation in international organisations, congresses and discussions on these subjects.

Engineering Public Relations Committee.

At the invitation of the Institution of Civil Engineers, an Engineering Public Relations Committee was formed with the object of drawing the attention of the public to the services rendered by Engineers and Engineering Science. The Institute, in addition to thirteen Societies and Institutions, is represented on the Committee.

Co-operation with Local Technical Societies.

Friendly co-operation with Local Technical Societies has been continued. Since the last Report arrangements for mutual co-operation have been made with the Ebbw Vale Metallurgical Society and the Swansea Technical College Metallurgical Society similar to those previously made with other Societies. These arrangements provide for the holding of joint meetings, the supply of papers presented to the Iron and Steel Institute for reading at meetings of the Local Societies when they so desire, and the extension of the maximum age of Associate Membership of the Institute from twenty-four to thirty in the case of those who are members of a Local Society.

The following is a list of the Societies with which arrangements on these lines have been concluded :

Cleveland Institution of Engineers.
Ebbw Vale Metallurgical Society.
Lincolnshire Iron and Steel Institute.
Manchester Metallurgical Society.
Newport and District Metallurgical Society.
Sheffield Metallurgical Association.
Sheffield Society of Engineers and Metallurgists.
Staffordshire Iron and Steel Institute.
Swansea Technical College Metallurgical Society.
West of Scotland Iron and Steel Institute.

The Council value the co-operation which has been established and wish to express their appreciation to the Council and Members of the Societies concerned; they believe that active co-operation of this kind is in the best interests both of the Societies concerned and of the Institute.

During the autumn and winter months the following joint meetings were held with the Societies named :

Thursday, October 14, 1937 : The Midland Metallurgical Societies.

Place and Time : The James Watt Institute, Great Charles Street, Birmingham, at 7 P.M.

Chairman : Mr. T. G. Bamford, President of the Staffordshire Iron and Steel Institute.

Paper : "Notes on Some Recent Experiments in Connection with the Spraying of Steel by the Wire-Fed Metal-Spraying Pistol," by Mr. R. R. Sillifant.

Tuesday, October 19, 1937 : The Lincolnshire Iron and Steel Institute.

Place and Time : The Modern School, Cole Street, Scunthorpe, at 7.30 P.M.

Chairman : Mr. W. B. Baxter, President of the Lincolnshire Iron and Steel Institute.

Report : "Reports upon Blast-Furnace Field Tests. I.—An Investigation of a Blast-Furnace Smelting principally Lincolnshire Ores at the Frodingham Works of the Appleby-Frodingham Steel Co., Ltd." Being a Report of the Blast-Furnace Reactions Research Sub-Committee to the Blast-Furnace Committee of the Iron and Steel Industrial Research Council. (*Special Report No.* 18.)

Tuesday, November 9, 1937 : The Staffordshire Iron and Steel Institute.

Place and Time : The Dudley and Staffordshire Technical Institute, Broadway, Dudley, at 7 P.M.

Chairman : Mr. T. G. Bamford, President of the Staffordshire Iron and Steel Institute.

Paper : "Some Experiments on the Influence of Silicon, Phosphorus and Manganese on Nitrogen-Hardening Cast Iron," by Mr. J. E. Hurst.

Tuesday, November 23, 1937 : The Sheffield Metallurgical Association and the Sheffield Society of Engineers and Metallurgists.

Place and Time : The Metallurgical Club, 198, West Street, Sheffield, at 7.30 P.M.

Chairman : Dr. W. H. Hatfield, F.R.S., Vice-President of the Iron and Steel Institute.

Papers :

"The Mechanism of Nitride-Hardening," by Dr. M. S. Fisher and Mr. Z. Shaw.

"Further Experiments on the Nitrogen-Hardening of High-Chromium and Austenitic Steels," by Mr. B. Jones.

"Some Alloys for Use at High Temperatures. Part IV.—The Constitution of the Alloys of Nickel, Chromium and Iron," by Dr. C. H. M. Jenkins, Mr. E. H. Bucknall, Dr. C. R. Austin and Mr. G. A. Mellor.

Monday, December 6, 1937 : The Cleveland Institution of Engineers.

Place and Time : The Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, at 7.30 P.M.

Chairman : Mr. A. Hutchinson, M.A., B.Sc., President of the Iron and Steel Institute.

Paper : "Hot Metal Practice in Five Melting Shops on the North-East Coast," by Mr. W. Geary.

Saturday, December 11, 1937 : The Newport and District Metallurgical Society and the Institute of British Foundrymen.

Place and Time : Newport Technical College, at 6.30 P.M.
Chairman : Mr. G. H. Latham, President of the Newport and District Metallurgical Society.
Report : "First Report of the Ingot Moulds Sub-Committee" (Section VI. of the Seventh Report on the Heterogeneity of Steel Ingots). Introduced by Mr. R. H. Myers, Chairman of the Sub-Committee, and presented for discussion by Mr. J. G. Pearce.

Friday, December 17, 1937 : The West of Scotland Iron and Steel Institute.

Place and Time : The Societies' Room, The Royal Technical College, George Street, Glasgow, at 7.15 P.M.
Chairman : Mr. Peter Ritchie, President of the West of Scotland Iron and Steel Institute.
Report : "Inclusions in a Series of Bath Samples from an Electric Furnace, and a Note on Sulphides" (Section IIIA. of the Seventh Report on the Heterogeneity of Steel Ingots), by Mr. J. H. Whiteley.

Wednesday, January 19, 1938 : The Manchester Metallurgical Society.

Place and Time : The Constitutional Club, St. Ann Street, Manchester, at 7 P.M.
Chairman : Mr. John E. James, Member of Council of the Iron and Steel Institute.
Paper : "Notes on some Recent Experiments in Connection with the Spraying of Steel by the Wire-Fed Metal-Spraying Pistol," by Mr. R. R. Sillifant.

Tuesday, February 15, 1938 : The Lincolnshire Iron and Steel Institute.

Place and Time : The Modern School, Cole Street, Scunthorpe, at 7.30 P.M.
Chairman : Mr. W. B. Baxter, President of the Lincolnshire Iron and Steel Institute.
Paper : "Hot Metal Practice in Five Melting Shops on the North-East Coast," by Mr. W. Geary.

Tuesday, March 15, 1938 : The Sheffield Metallurgical Association and the Sheffield Branch of the Institute of British Foundrymen.

Place and Time : The Metallurgical Club, 198, West Street, Sheffield, at 7.30 P.M.
Chairman : Professor J. H. Andrew.
Report : "First Report of the Ingot Moulds Sub-Committee" (Section VI. of the Seventh Report on the Heterogeneity of Steel Ingots). Introduced by Mr. R. H. Myers, Chairman of the Sub-Committee, and presented for discussion by Mr. J. G. Pearce.

The Meetings were well attended and the interest shown in the reports and papers was gratifying. The Council wish to record their appreciation to the Presidents, Councils and Secretaries of the Local Societies, as well as to the authors of papers, for their contributions to the success of the Meetings.

Papers and Special Reports.

The following twenty-one papers, four Special Reports and two Supplementary Reports were published during the year:

Special Report No. 16.—"Seventh Report on the Heterogeneity of Steel Ingots."

Special Report No. 17.—"The Work of the Coke Research Committees of the Iron and Steel Industrial Research Council." By E. C. Evans and J. M. Ridgion.

Special Report No. 18.—"Reports upon Blast-Furnace Field Tests. I.—An Investigation of a Blast-Furnace Smelting principally Lincolnshire Ores at the Frodingham Works of the Appleby-Frodingham Steel Co., Ltd."

Special Report No. 19.—"Foamed Blast-Furnace Slag." By T. W. Parker.

Special Report No. 14A.—"Discussion, Correspondence and Reply on 'First Report of the Alloy Steels Research Committee.'"

Special Report No. 15A.—"Discussion, Correspondence and Reply on 'Second Report of the Steel Castings Research Committee.'"

Adcock, F.—"An Investigation of the Iron-Carbon Constitutional Diagram. Part I.—Preliminary Survey of the δ Region."

Blayden, H. E., W. Noble and H. L. Riley.—"Some Experiments in a Small-Scale Cupola."

Blayden, H. E., W. Noble and H. L. Riley.—"The Influence of Carbonising Conditions on Coke Properties. Part I.—Mechanical Pressure."

Brennert, Sven.—"Method for Testing the Resistance of Stainless Steels to Local Corrosive Attack."

Britton, S. C.—"Some Properties of Commercial Steel Sheets Containing Additions of Copper, Manganese, Chromium and Phosphorus."

Fisher, M. S., and Z. Shaw.—"The Mechanism of Nitride-Hardening."

Gayler, Marie L. V., and C. Wainwright.—"Alloys of Iron Research. Part XII.—Note on the β_M Transformation in Manganese-Rich Iron-Manganese Alloys."

Geary, W.—"Hot Metal Practice in Five Melting Shops on the North-East Coast."

Gough, H. J., F.R.S., and D. G. Sopwith.—"The Influence of the Mean Stress of the Cycle on the Resistance of Metals to Corrosion-Fatigue."

Hadfield, Sir Robert, Bt., F.R.S., and S. A. Main.—"A Practical Trial of Roofing Sheets of Copper Steels and other Materials."

Harbord, F. W., C.B.E.—"The Thomas-Gilchrist Basic Process, 1879–1937."

Hoare, W. E.—"Variation in Thickness of the Tin Coating of Tinplate, and its Effect on Porosity."

Hurst, J. E.—"Some Experiments on the Influence of Silicon, Phosphorus and Manganese on Nitrogen-Hardening Cast Iron."

Jenkins, C. H. M., E. H. Bucknall, C. R. Austin and G. A. Mellor.—"Some Alloys for Use at High Temperatures. Part IV.—The Constitution of the Alloys of Nickel, Chromium and Iron."

Jones, B.—"Further Experiments on the Nitrogen-Hardening of High-Chromium and Austenitic Steels."

Jones, J. A.—"The Effect of Phosphorus on the Mechanical and Corrosion-Resisting Properties of Low-Carbon and of Low-Alloy Structural Steels."

Klärding, N. J.—"A New Method for Judging the Behaviour of Iron Ores during Reduction."

O'Neill, H.—"Alloy and Fine-Grained Steels for Locomotive Coupling Rods."

Portevin, A. M., and René Castro.—"Morphology of the Inclusions in Siderurgical Products.—Parts IV. and V."

SILLIFANT, RICHARD R.—"Notes on Some Recent Experiments in Connection with the Spraying of Steel by the Wire-Fed Metal-Spraying Pistol."

SOPWITH, D. G., and H. J. GOUGH, F.R.S.—"The Effect of Protective Coatings on the Corrosion-Fatigue Resistance of Steel."

The following communication was also printed in the Journal:

RICHER, G. C.—"A Note on the Influence of Grain Size on Magnetic Hysteresis."

Volume XXVI. of the *Carnegie Scholarship Memoirs* was published in respect of 1937, and contained the following Reports:

ADAMS, L. E.—"The Effects of Torsional Overstrain on the Physical Properties of Some Typical Springs Steels, and its Influence on the Shear Stresses in Helical Springs."

BOOTH, C., and W. J. REES.—"Investigations on Basic Refractories with particular Reference to their Use in the Lining of Induction Furnaces."

FELL, ERIC W.—"'Yielding' Phenomena and Distortion in Iron, Steel, Aluminium Alloy and other Metals under Stress."

GRIFFITHS, R.—"The Relationship between the Microstructure and the Adherence of Scale Deposit."

PUBLICATIONS.

Two volumes of the *Journal*, a volume of *Carnegie Scholarship Memoirs*, four Special Reports—the latter consisting of the Seventh Report on the Heterogeneity of Steel Ingots, the Work of the Coke Research Committees of the Iron and Steel Industrial Research Council, Reports upon Blast-Furnace Field Tests, Part I., and Foamed Blast-Furnace Slag—and two Supplementary Reports—Discussion, Correspondence and Committees' Replies on the First Report of the Alloy Steels Research Committee and the Second Report of the Steel Castings Research Committee—were published during the year.

The monthly *Bulletin of the Iron and Steel Institute* has also been published during the year, and is available to all Members on application without charge. A List of Members was issued.

ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

Grants were made by the Council in 1937 to the following candidates:

G. E. A. BRAMLEY (The University, Sheffield).—£100 in aid of a research on the oxygen content of steel.

P. T. CARTER (Armstrong College, Newcastle-on-Tyne).—£100 for an investigation of the properties of graphite. (Second grant.)

H. A. MILEY (The University, Cambridge).—£100 in aid of a research on the thickness of thin oxide films on iron and the law of growth at ordinary temperature. (Second grant.)

G. T. RICHARDSON (The University, Leeds).—£50 in aid of a research on the influence of varying atmospheres on steels. (Third grant.)

(The above researches are being carried out on behalf of the Joint Research Committees of the Iron and Steel Industrial Research Council and the Institute.)

G. M. Dyson (Loughborough College).—£50 in aid of a research on the distribution of gases in cast iron, and the influence of founding and pouring methods on the structure, composition and gaseous distribution in cast iron. (Second grant.)

E. Hoesch (Eisenhüttenmännisches Institut der Technischen Hochschule Berlin).—£100 in aid of an investigation on the breakdown of alitised, that is, aluminium-coated, coatings on cast iron and steel.

J. A. Verö (Sopron, Hungary).—£100 for an investigation of the dependence of the structure of cast steel on the rate of cooling.

J. White (Drumchapel, Glasgow).—£100 in aid of a research on equilibria at high temperatures in melts containing ferric oxide. (Second grant.)

Andrew Carnegie Gold Medal for 1937.

For the year 1937 no award of the Andrew Carnegie Medal was made.

Williams Prize for 1937.

The Williams Prize was awarded to Mr. W. Geary for his paper on "Hot Metal Practice in Five Melting Shops on the North-East Coast," which was published in the No. II. volume of the *Journal of the Iron and Steel Institute* for 1937.

The Council are gratified that after an interval of three years this Prize has again been awarded, especially as they consider the paper to be of high merit and an excellent example of the type of paper which it was the object of the Prize to encourage.

Library.

The Council have endeavoured to maintain, and increase, the usefulness of the Library and the information services operated by the Library Department for the benefit of Members. During the year under review the Library has been enriched by the addition of a number of important text books, and the Council take this opportunity to extend thanks on behalf of the Members to those authors who have presented copies of their works to the Library.

Members have been kept informed of developments in iron and steel manufacture and ferrous metallurgy by means of the *Bulletin of the Iron and Steel Institute*, which contains abstracts of all the important technical literature.

The majority of the articles abstracted in the *Bulletin* are filed in the Library and are available for loan. The original articles can be purchased for Members on request, and photographic copies can be supplied under certain conditions.

In addition to the Institute's Library, the valuable collection of scientific works included in the Science Library, South Kensington, is available for loan by kind permission of the Director of the Science Library.

A list of the additions made to the Library is issued quarterly, and copies will be sent to Members on request.

The work of the Information Department has included the preparation of a number of bibliographies, which can be supplied

to Members at 1*s*. each on request. The following bibliographies were prepared during the year :

No. 4. "Influence of Arsenic and Tin on the Properties of Iron and Steel. Part I.—Arsenic (Covering the period 1864 to 1936). Part II.—Tin (Covering the period 1901 to 1936)."
No. 5. "Manufacture, Properties and Testing of Steel Castings (not including Moulding Sands) (Covering the period 1920 to 1937)."
No. 6. "Gas Producer Practice (Covering the period 1902 to 1936)."
No. 7. "Flakes (Hair-Cracks, Snowflakes), Ghost Lines, Banded Structure and Fissures in Steel (Covering the period 1918 to 1937)."

The following translations were prepared, and copies are available for consultation in the Library or for purchase at a nominal cost :

No. 8. "Heat Conductivity of Steels Containing Chromium at High Temperature." By E. Maurer. (Translated from the German).
No. 9. "Oxygen-Enriched Blast in the Blast-Furnace Process." By C. Messerle. (Translated from the Russian).
No. 10. "The Formation of Inclusions in Steel." By H. Wentrup. (Translated from the German).
No. 11. "Roller Straightening Machines." By L. Reichert. (Translated from the German).

Iron and Steel Industrial Research Council.

Collaboration with the Iron and Steel Industrial Research Council has been maintained, and the Institute has continued to take an important part in the joint research activities of the industry. The Council wish to record their appreciation of the assistance given by the Department of Scientific and Industrial Research to scientific and technical development in the industry, and to the British Iron and Steel Federation and the Iron and Steel Industrial Research Council for their valuable co-operation. They wish also to thank the Associations, Companies and individuals who have contributed generously in time and money to research, and to express their appreciation of the valuable work which is being done by many Government, University, industrial and private laboratories.

Research Committees.

The following Committees and Sub-Committees are Joint Committees of the Institute and the Iron and Steel Industrial Research Council engaged on co-operative research :

Alloy Steels Research Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established June, 1934. Meetings held during 1937, seven.

Sub-Committee A, Thermal Treatment; Chairman, Mr. P. B. Henshaw. Established January, 1936. Meetings held during 1937, five.

Corrosion Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1928. Meetings held during 1937, seven.

Laboratory Research Sub-Committee; Chairman, Dr. U. R. Evans. Established June, 1930. Meetings held during 1937, nil.

Protective Coatings Sub-Committee; Chairman, Mr. T. M. Herbert. Established January, 1936. Meetings held during 1937, six.

Heterogeneity of Steel Ingots Committee; Chairman, Dr. W. H. Hatfield, F.R.S. Established May, 1924. Meetings held during 1937, seven.

Liquid Steel Temperature Sub-Committee; Chairman, Mr. E. W. Elcock. Established March, 1929. Meetings held during 1937, three.

Ingot Moulds Sub-Committee (joint with the Open-Hearth Committee of the Iron and Steel Industrial Research Council); Chairman, Mr. R. H. Myers. Established November, 1934. Meetings held during 1937, three.

Oxygen Sub-Committee; Chairman, Dr. T. Swinden. Established January, 1936. Meetings held during 1937, two. (Numerous meetings of Panels were held.)

Sub-Committee on Inclusions; Chairman, Dr. W. H. Hatfield, F.R.S. Established November, 1936. Meetings during 1937 not recorded.

Steel Castings Research Committee; Chairman, Mr. W. J. Dawson. Established November, 1934. Meetings held during 1937, five.

Moulding Materials Sub-Committee; Chairman, Mr. W. J. Rees. Established March, 1936. Meetings held during 1937, five.

The Seventh Report on the Heterogeneity of Steel Ingots was published at the Annual Meeting, 1937.

The Worshipful Company of Blacksmiths.

In accordance with the understanding with the Wardens of the Worshipful Company of Blacksmiths, applications for nomination for admission to the Company were considered, and Mr. A. McNeil, of Glasgow, and Mr. Eric A. Robinson, of London, were recommended by the Council for admission to the Company.

Appointment of Representatives.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1937; it has been brought up to date to March 31, 1938:

British Association, Fuel Economy Committee: Sir Robert Hadfield, Bt., F.R.S.

British Cast Iron Research Association: Professor T. Turner.

British Corporation Register of Shipping and Aircraft, Committee of Management and Technical Committee: Dr. A. McCance.

British Electrical and Allied Industries Research Association,

Sub-Committee J/E, Joint Committee, Steels for High Temperatures: Dr. W. H. Hatfield, F.R.S., Dr. T. Swinden.

Sub-Committee J, Earthing to Water Mains: Dr. J. C. Hudson.

British Iron and Steel Federation, Statistical Committee: Mr. K. Headlam-Morley.

British Refractories Research Association, Council: Mr. F. W. Harbord, C.B.E.

BRITISH STANDARDS INSTITUTION,
Chemical Engineering Divisional Council : Mr. E. F. Law.
Engineering Divisional Council E/- : Mr. T. W. Hand, Mr. W. J. Brooke, Mr. James Henderson.
Sub-Committee M33/7, Protective Glasses for Welders and Industrial Purposes : Dr. C. H. Desch, F.R.S.
Technical Committee B/16, Breeze and Clinker Slabs : Mr. F. W. Harbord, C.B.E.
Technical Committee EL/28, Fans : Mr. A. F. Webber.
Iron and Steel Industry Committee IS/- : Dr. T. Swinden.
Technical Committee IS/1, Co-ordination of Iron and Steel Specifications : Dr. T. Swinden.
Technical Committee IS/6, Steel Castings : Dr. R. H. Greaves.
Technical Committee IS/8, Creep Properties : Dr. W. H. Hatfield, F.R.S.
Technical Committee IS/15, Iron and Steel for Shipbuilding : Mr. E. J. George.
Technical Committee IS/35, Cast Iron : Mr. H. B. Toy.
Technical Committee ME/22, Marking and Colouring of Foundrymen's Patterns : Mr. F. W. Lewis.
Technical Committee ME/23, Brinell Hardness Testing : Dr. W. H. Hatfield, F.R.S.
Technical Committee ME/25, Testing of Thin Metal Sheet and Strip : Dr. T. Swinden.
Technical Committee ME/32, Engineering Symbols and Abbreviations : Dr. T. Swinden.
Public Works Industry Committee PW/- : Mr. James Henderson.
Technical Committee PW/34, Portland Blast-Furnace Cement : Mr. F. W. Harbord, C.B.E.
Solid Fuel Industry Committee, SF/- : Mr. A. F. Webber.
Technical Committee SF/1, Nomenclature and Definitions : Mr. A. F. Webber.
Technical Committee SF/2, Underfeed Screw Type Stokers : Mr. A. F. Webber.
Technical Committee SF/4, Heating Stoves : Mr. A. F. Webber.
Units and Technical Data Co-ordinating Committee : Sir Wm. Larke, K.B.E.

CITY AND GUILDS OF LONDON INSTITUTE,
Advisory Committee on Metallurgy : Mr. E. C. Greig.
Examiner in Iron and Steel Manufacture : Professor W. H. Merrett.

CONSTANTINE COLLEGE, Advisory Committee : Mr. E. W. Jackson.

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH, Grey and Malleable Cast Iron Research Committee : Professor T. Turner.

EMPIRE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS : Mr. F. W. Harbord, C.B.E., Mr. K. Headlam-Morley.

ENGINEERING PUBLIC RELATIONS COMMITTEE,
Main Committee : Mr. A. Hutchinson.
Executive Committee : Mr. K. Headlam-Morley.

HONG KONG UNIVERSITY, Home Committee : Sir Robert Hadfield, Bt., F.R.S.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, Board of Governors : Mr. B. Talbot.

IMPERIAL INSTITUTE, Mineral Resources Department, Iron and Ferro-Alloy Metals Committee : Mr. K. Headlam-Morley.

INSTITUTE OF FUEL, Council : Mr. F. W. Harbord, C.B.E.

INSTITUTE OF WELDING, LTD., Council and Representative of Patron Institution : Mr. K. Headlam-Morley.

INSTITUTION OF MECHANICAL ENGINEERS, Research Committee on High-Duty Cast Irons for General Engineering Purposes : Mr. K. Headlam-Morley.

IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL : Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield, F.R.S., Mr. K. Headlam-Morley.

JOINT COMMITTEE ON MATERIALS AND THEIR TESTING : Mr. K. Headlam-Morley.

LIVERPOOL UNIVERSITY, Court of Governors : Sir W. Peter Rylands.

LLOYD'S REGISTER OF SHIPPING, Technical Committee : Mr. James Henderson, Mr. P. Baxter.

MECHANISATION BOARD (Army Council) : Mr. F. W. Harbord, C.B.E.

METALLIFEROUS MINING AND QUARRYING INDUSTRIES, Advisory Committee : Professor H. Louis, M.A., D.Sc.

MINISTRY OF AGRICULTURE AND FISHERIES, Permanent Committee on Basic Slag : Mr. James Henderson, Mr. B. Talbot.

NATIONAL PHYSICAL LABORATORY,
General Board : Dr. A. McCance, Dr. T. Swinden.
Alloys of Iron Research Committee : Mr. F. W. Harbord, C.B.E.

RAMSEY MEMORIAL LABORATORY, Advisory Committee : Mr. F. W. Harbord, C.B.E.

ROYAL SCHOOL OF MINES, Advisory Board : Mr. F. W. Harbord, C.B.E.

ROYAL SOCIETY, General Board for Administering Government Grants for Scientific Investigations : The President.

SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors : Professor H. Louis, M.A., D.Sc.

SCIENCE MUSEUM, Advisory Council : Sir Harold Carpenter, F.R.S.

SHEFFIELD UNIVERSITY, Court of Governors : Sir Robert Hadfield, Bt., F.R.S.

[The Statement of Accounts for 1937 will be found in the following pages.]

THE IRON AND

BALANCE SHEET,

LIABILITIES.

	£ s. d.	£ s. d.
Sundry Creditors :—		
Office Rent	203 19 0	
Telephone Calls	8 11 3	
Printing and Stationery	17 16 6	
Corrosion Committee	8 1 8	
Alloy Steels Committee	1 13 7	
Ingot Committee	1 13 7	
Steel Castings Committee	25 0 0	
Bulletin	95 3 10	
Autumn Meeting	78 11 0	
Library Books	1 0 7	
Office Furniture	6 1 6	
Institute of Metals	2 12 6	
Carnegie Scholarship Fund *re* I.S.I.R.C....	200 0 0	
		650 5 0
Subscriptions in Advance :—		
Home Members	84 0 0	
Overseas Members	98 4 9	
Associate Members	13 2 6	
		195 7 3
Entrance Fees in Advance		4 4 0
Journal Sales :—		
Amount in Advance, 1938...	341 16 10	
Received on Account, No. II., 1937 ...	68 11 10	
Sundries	5 3	
		410 13 11
Suspense Account as at 1st January, 1937 :—		
£ s. d.		
Reserve for 10-Year Index 100 0 0		
Add Further transfer, 1937 50 0 0		
	150 0 0	
Entrance Fees 898 9 0		
Add Further transfer, 1937 312 18 0		
	1,211 7 0	
		1,361 7 0
Life Composition Fund		3,146 13 5
Iron and Steel Institute :—		
Capital and Reserve Account—		
Capital as per last Balance Sheet ...	23,873 12 4	
Reserve Account—		
Accumulated Excess of Income over Expenditure, &c. :— £ s. d.		
As at 1st January, 1937 3,843 1 3		
Less Entertainment of Foreign Members ... 645 13 9		
3,197 7 6		
Excess of Income over Expenditure for the Year to date ... 628 3 1		
	3,825 10 7	
		27,699 2 11
		£33,467 13 6

I have examined the above Balance Sheet

STEEL INSTITUTE.

31ST DECEMBER, 1937.

ASSETS.

	£ s. d.	£ s. d.
Sundry Debtors :—		
Subscriptions in Arrear		Not Valued
Journal Sales	191 8 1	
Amount due from Carnegie Scholarship Fund	321 12 9	
Telephone Deposit	1 0 0	
Autumn Meeting	284 17 5	
I.A.T.M. Loan Account	35 9 9	
Corrosion Committee	111 4 5	
Do. Birmingham Office	96 1 11	
Advance Copies	129 18 9	
Alloy Steels Research Committee ...	190 0 0	
Appeal Fund	225 0 0	
Life Composition Fund—Amount over-invested	2 8 9	
		1,589 1 10
Payments in Advance :—		
Journal Printing	37 13 6	
Translations and Reviews	16 13 0	
Insurance	5 2 3	
Library Books	27 10 2	
Staff Superannuation Fund	172 19 10	
Sundries	2 4 2	
		262 2 11
Stock of Journals		Not Valued.
Office Furniture and Library		Not Valued.
Investments at Cost per Schedule :—		
General Fund		24,896 5 4
(The Market Value of these Investments at 31st December, 1937, was £28,307 3*s.* 7*d.*)		
Cash at Bank and in Hand :—		
Current Account	866 18 6	
Secretary's Account	96 5 0	
Deposit Account	1,000 0 0	
Do. Post Office Account ...	1,303 10 3	
Deposit, Banque de Plovdiv, Bulgaria ...	5 5 0	
Cash at Office	26 0 0	
		3,297 18 9
Research Committees :—		
Grants due	3,250 0 0	
Deduct Amount of Grant unexpended during Year	1,371 11 9	
	1,878 8 3	
Less Contributions collected :—		
£ s. d.		
Corrosion Research Committee 100 0 0		
Steel Castings Committee 2 2 0		
Alloy Steels Committee ... 1,500 15 0		
	1,602 17 0	
		275 11 3
Life Composition Fund :—		
Investments at Cost per Schedule ...		3,146 13 5
(The Market Value of these Securities at 31st December, 1937, was £3,264 6*s.* 10*d.*)		
		£33,467 13 6

of the Institute and certify it to be correct.

(*Signed*) W. B. KEEN,
Chartered Accountant.

INCOME AND EXPENDITURE ACCOUNT

INCOME.

	£ s. d.	£ s. d.
To Entrance Fees	136 10 0	
Do. Companies' Nominations	176 8 0	
	312 18 0	
Less Transferred to Reserve Account	312 18 0	
		...
,, Annual Subscriptions :—		
Members, Home—Current	3,953 5 0	
Do. Companies' Nominations	226 16 0	
Arrears	155 18 6	
		4,335 19 6
Members, Overseas—Current	1,642 8 3	
Do. Companies' Nominations	31 10 0	
Arrears	97 17 9	
		1,771 16 0
Associates—Current	143 17 0	
Do. Companies' Nominations ...	24 3 0	
		168 0 0
,, Sales of Publications :—		
Journals, etc.	1,498 1 9	
Bulletin	43 2 11	
		1,541 4 8
,, Interest on Investments (*less* Tax) :—		
General Fund	952 13 11	
Life Composition Fund	100 13 5	
Bessemer Medal Fund	12 2 0	
		1,065 9 4
,, Interest on Deposit Accounts		32 11 9
,, Sundry Receipts		7 0 0
,, Income Tax recovered, 1936–37 :—		
General Fund	119 15 0	
Life Composition Fund	15 16 4	
Bessemer Medal Fund	3 16 0	
		139 7 4
,, I.S.I.R.C. :—		
Grant for Bulletin	750 0 0	
Grant for Secretarial Services ...	2,000 0 0	
Grant for Information Service ...	500 0 0	
Grant by Carnegie Research Fund ...	400 0 0	
	3,650 0 0	
Less Amount to be repaid to Carnegie Research Fund in respect of their contribution towards Expenditure...	200 0 0	
		3,450 0 0
,, Welding Symposium :—		
Sales of Volumes	150 11 11	
Less Printing	1 18 3	
		148 13 8
,, Balance, being excess of Expenditure over Income carried down ...		1,864 9 11
		£14,524 12 2
To Special Subscriptions :—		
Contributions received during 1937 ...		3,001 10 0
		£3,001 10 0

STATEMENT OF ACCOUNTS.

FOR THE YEAR ENDED 31ST DECEMBER, 1937.

EXPENDITURE.

	£	s.	d.	£	s.	d.
By Salaries (including Pensions and Overtime)				5,334	4	3
,, National Insurance				36	17	3
,, Staff Superannuation Fund				291	17	4
,, Office Rent, Cleaning, Decorating, &c. ...				923	3	3½
,, Library Books, Binding, &c.				189	17	9
,, Office Furniture				39	15	3
,, Annual Meeting				302	5	11
,, Autumn Meeting				391	12	4
,, Publishing Expenses :—						
Journal—						
Printing and Paper	1,658	6	3			
Translations and Reviews	148	19	10			
Postage	210	0	5			
Advance Copies—Printing	206	18	3			
Postage	120	2	2			
Bulletin—Printing	463	17	1			
Postage	83	19	6			
Bibliographies	18	13	7			
List of Members	121	11	0			
				3,032	8	1
,, Stationery and Printing				460	3	9
,, Postage and Receipt Stamps				208	18	9
,, Travelling and Entertainment Expenses				220	1	3
,, Insurance				8	14	3
,, Auditor's Fee				46	4	0
,, Telephone Rental and Calls				66	16	3
,, Bessemer Medal				41	15	0
,, Office Disbursements and Sundry Expenses				184	18	2½
,, Translations Service				44	19	11
,, Grants :—						
Joint Committee on Materials and their Testing	10	10	0			
Electrodeposition Conference	5	5	0			
Status of Engineers	18	13	10			
Institution of Automobile Engineers Joint Conference	5	0	6			
British Refractories Research Association	25	0	0			
Institution of Mechanical Engineers—High Duty Cast Iron	25	0	0			
British Electrical and Allied Industries Research Association—Research on Steels for Use at High Temperatures	50	0	0			
British Standards Institution	50	0	0			
British Foundry School	10	10	0			
				199	19	4
,, I.S.I.R.C. :—						
Grant by I. & S.I. *re* Research Committees				2,500	0	0
				£14,524	12	2
By Balance brought down				1,864	9	11
,, Transfer Reserve Account :—						
10 Years Index				50	0	0
Entrance Fees				176	8	0
,, Transfer Subscription Account :—						
Home Members				226	16	0
Overseas Members				31	10	0
Associates				24	3	0
,, Balance, being excess of Income over Expenditure carried to Balance Sheet				628	3	1
				£3,001	10	0

WILLIAMS PRIZE FUND.

BALANCE SHEET, 31ST DECEMBER, 1937.

LIABILITIES.	£ s. d.	£ s. d.
Capital Account representing the Market Value of £3,000 3½% Conversion Loan at 21st September, 1926, when Fund was Inaugurated		2,220 0 0
Income and Expenditure Account :—		
Balance as at 1st January, 1937	384 12 7	
Add Excess of Income over Expenditure for the year to 31st December, 1937 ...	111 19 6	
		496 12 1
		2,716 12 1
		£2,716 12 1

ASSETS.	£ s. d.	£ s. d.
£3,000 3½% Conversion Loan (at Cost) ...	2,220 0 0	
Cash at Bank	210 0 1	
		2,430 0 1
(The Market Value of this Security at 31st December, 1937, was £3,075 0*s.* 0*d.*)		
Deposit Account—P.O. Savings Account ...		286 12 0
		£2,716 12 1

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1937.

INCOME.	£ s. d.	£ s. d.
To Interest on 3½% Conversion Stock	105 0 0	
,, Do. Deposit Post Office Account	6 19 6	
	£111 19 6	

EXPENDITURE.	£ s. d.
By Excess of Income over Expenditure carried to Balance Sheet	111 19 6
	£111 19 6

CARNEGIE RESEARCH SCHOLARSHIP FUND.

BALANCE SHEET, 31ST DECEMBER, 1937.

LIABILITIES.	£ s. d.	£ s. d.
Sundry Creditors :—		
Grants	250 0 0	
Amount due to General Fund	321 12 9	
Auditor's Fees	10 10 0	
Tibor Ver's Account	5 12 1	
		587 14 10
Amount of Original Fund ($100,000) ...	21,241 5 6	
Add Amounts since capitalised	2,912 9 6	
	24,153 15 0	
	£ s. d.	
Add Surplus Income as at 1st January, 1937	1,337 6 6	
Deduct Excess of Expenditure over Income for the Year	1 16 10	
	1,335 9 8	
		25,489 4 8
		£26,076 19 6

ASSETS.	£ s. d.	£ s. d.
Investments at Cost per Schedule ... ... (The Market Value of these Investments at 31st December, 1937, was £31,454 14*s.* 3*d.*)		25,355 16 10
Cash at Bank :—		
On Current Account	241 11 7	
Post Office Savings Account	258 18 1	
		500 9 8
Payments in Advance		20 13 0
Sundry Debtors :—		
General Fund Research Committees ...		200 0 0
		£26,076 19 6

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1937.

INCOME.	£ s. d.
To Interest on Investments (*less* Tax)	983 11 0
,, Income Tax recovered, 1936–37	162 19 8
,, Interest on Deposit	6 6 0
,, Balance, being excess of Expenditure over Income carried to Balance Sheet	1 16 10
	£1,154 13 6

EXPENDITURE.	£ s. d.	£ s. d.	£ s. d.
By Scholarship Grants		375 0 0	
Do. I.S.I.R.C. ...	400 0 0		
Less Refund by General Fund of the Iron and Steel Institute	200 0 0		
		200 0 0	
			575 0 0
,, Salaries			104 0 0
,, Sundries			13 0
,, Audit Fee			10 10 0
,, Medal			6 0 3
,, Printing Memoirs, Vol. 25			458 10 3
			£1,154 13 6

IRON AND STEEL INSTITUTE.

SCHEDULE OF INVESTMENTS AT 31ST DECEMBER, 1937.

SHOWING NOMINAL VALUES, COST VALUES AND PRESENT MARKET VALUES.

GENERAL FUND OF THE INSTITUTE.

Nominal Value.	Nature of Security.	Market Value, 31st December, 1937.	Cost Price.
£ s. d.		£ s. d.	£ s. d.
2,197 7 0	3½% War Stock ...	2,235 16 0	2,161 0 8
324 7 4	3½% Conversion Loan ...	332 9 6	231 1 0
447 0 0	Southern Railway 4% Debenture Stock ...	476 1 1	449 2 4
1,872 0 0	London and North Eastern Railway 4% 2nd Guaranteed Stock ...	1,675 8 10	2,149 13 3
2,241 0 0	Do. do. 4% 1st do. ...	2,140 3 1	2,431 14 5
1,500 0 0	Buenos Ayres Great Southern Railway 4% Debenture Stock ...	1,140 0 0	1,594 12 9
1,000 0 0	Calcutta Bonds 4%, 1939 ...	1,040 0 0	982 10 0
800 0 0	Bombay Bonds 4%, 1939 ...	828 0 0	809 0 0
2,954 1 0	4% Consolidated Stock ...	3,262 7 0	3,175 18 1
437 0 0	London and North Eastern Railway 3% Debenture Stock ...	347 19 2	376 12 5
12,242 19 3	4% Funding Loan, 1960–90 (transferred from Special Purposes Fund) ...	13,803 18 11	9,512 7 5
1,000 0 0	3½% Conversion Loan ...	1,025 0 0	1,022 13 0
		£28,307 3 7	£24,896 5 4

LIFE COMPOSITION FUND.

386 6 0	3½% Conversion Loan ...	395 19 2	304 10 0
1,330 0 0	London and North Eastern Railway 3% Debenture Stock ...	1,059 0 3	1,254 17 6
594 0 0	London Passenger Transport Board 4½% "A" Stock (July 1923) ...	697 19 0	638 6 1
130 4 8	3½% Conversion Loan ...	133 9 10	137 11 0
143 6 0	3½% War Loan ...	145 16 1	146 10 7
681 13 0	4% Funding Loan ...	768 11 2	600 0 0
62 19 6	3½% War Loan ...	63 11 4	64 18 3
		£3,264 6 10	£3,146 13 5

Nominal Value.	Nature of Security.	Market Value, 31st December 1937.	Cost Price.
£ s. d.		£ s. d.	£ s. d.
CARNEGIE FUND OF THE INSTITUTE.			
6,897 14 11	3½% War Stock	7,018 9 2	6,895 16 6
2,693 12 0	3½% Conversion Loan	2,760 18 10	2,006 19 0
227 9 4	3% Local Loans	198 9 3	202 10 0
2,300 0 0	India 3½% Stock 1931	2,139 0 0	1,600 2 9
2,560 4 0	Do. 3% do. 1948	2,035 7 2	1,525 3 3
2,250 0 0	North Eastern Electric Supply Co. 3½% Consolidated Debenture Stock	2,279 10 8	2,261 10 0
1,500 0 0	Great Western Railway 4% Debenture Stock	1,657 10 0	1,204 5 3
2,000 0 0	London, Midland and Scottish Railway 4% Debenture Stock	2,110 0 0	1,693 0 6
1,312 0 0	London and North Eastern Railway 4% 1st Guaranteed Stock	1,252 19 2	880 11 11
5,000 0 0	Do. do. 4% Debenture Stock	5,225 0 0	3,540 8 5
6,000 0 0	Do. do. 3% do.	4,777 10 0	3,545 9 3
		£31,454 14 3	£25,355 16 10
INVESTMENT ON ACCOUNT OF WILLIAMS PRIZE FUND.			
3,000 0 0	3½% Conversion Loan	3,075 0 0	2,220 0 0
BESSEMER MEDAL FUND.			
	Trustees:—Sir Harold Carpenter, Lord Airedale and Frank Samuelson, Esq.		
400 0 0	London, Midland and Scottish Railway 4% Debenture Stock	£422 0 0	

(*Signed*) JAMES HENDERSON,
Hon. Treasurer.

(*Signed*) K. HEADLAM-MORLEY,
Secretary.

I have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Investments shown above.

23 QUEEN VICTORIA STREET,
LONDON, E.C. 4.
8th March, 1938.

(*Signed*) W. B. KEEN,
Chartered Accountant.

PRESIDENTIAL ADDRESS.

By The Right Hon. THE EARL OF DUDLEY, M.C.

I believe I am right in saying that never before have you been addressed by a President who is actively engaged in the manufacture of iron and steel in the South Staffordshire district, and so, in the first place, I should like to tell you how deeply I appreciate the honour paid to me in being elected your President—an honour which I share with the district that I am proud to represent, and with which my family have had such close associations for many centuries.

I propose to give a short survey of the iron and steel industry with a special reference to my own district. One sometimes hears the opinion that, as an iron and steel making district, South Staffordshire, or, as it is more usually called, the Birmingham district, has had its day; that it is looked upon as having had a glorious past—in fact having been the cradle of the industry not only of Great Britain but of the whole world—and that to-day as an iron and steel producing district it is gradually fading into insignificance. I by no means share that view.

It is true that the history of iron and steel making is wrapped up in the history of South Staffordshire. It would make too long a story to enumerate all those who are entitled to be included in the list of pioneers of our industry, but the history of iron and steel manufacture in South Staffordshire from the time of my ancestor, Dud Dudley, born in 1618, makes interesting reading, as it traces the progress made by the various processes and plants engaged in the production of pig iron, wrought iron and steel. To mention a few of the most famous pioneers; Dud Dudley was the author of "Mettallum Martis," printed in 1665, and therein may be found an interesting account of the iron trade of those times; it records the great difficulties which had to be surmounted before coal could be successfully used instead of charcoal for the purpose of smelting iron. Another pioneer was Abraham Darby, who first used coke in the blast-furnace instead of coal; he was an ironmaster of Dudley, who afterwards moved to Coalbrookdale. His grandson, Abraham Darby, there built the first iron bridge, which is still in use and spans the river Severn at Ironbridge. It was opened for traffic in 1779. The main arch has a clear span of 100 ft.; the weight of metal, including the cast-iron plates in the bridge, amounts to 308 tons. It is now scheduled as an ancient monument by the Office of Works.

In 1783, Henry Cort, an ancestor of a recent President, introduced the use of grooved rolls in rolling mills, and in the following year invented the dry puddling process. Later, about 1820,

Joseph Hall, of Tipton, a South Staffordshire man, improved on this process by introducing wet puddling, or " pig boiling," so that the wrought iron trade of the district grew rapidly and spread to other districts. An increased production of pig iron naturally followed and resulted in an increase in the number of furnaces in blast throughout the country, so that by 1825 there were 374 blast-furnaces in Great Britain, of which 262 were in blast, producing 581,000 tons of pig iron ; the average output was about 45 tons per furnace per week.

About this time the great industrial development of this country began, largely due to the dawn of the steam age which brought with it a rapid development of the steam engine and the building of railways, so that increased iron production followed, and by the year 1861—according to statistics published in Samuel Griffith's *Iron Trade Circular*—there were 565 blast-furnaces in blast in the whole of Great Britain, and they produced 3,986,320 tons of pig iron, of which 933,660 tons were produced in the South Staffordshire area. This was an average of 135 tons per furnace per week compared with 45 tons per week in 1825.

According to the same statistics, the amount of pig iron produced in England alone was 2,060,760 tons, which entailed a consumption of 12 million tons of coal, 9 million tons of ironstone and 3 million tons of limestone. This enormous consumption of fuel per ton of pig iron produced would certainly shock the modern fuel expert, but doubtless must have gladdened the hearts of the coal owners of those days.

In the same statistics it is recorded that in 1861 there were 1,768 puddling furnaces in operation in different works in the South Staffordshire area alone, owned by eighty different firms.

We now come to the modern steel age, which owes its inception to two fundamental inventions ; that of Henry Bessemer, who invented the Bessemer process in 1856, and that of Charles William Siemens, who introduced the open-hearth process in 1861. The development of these two processes in the course of time had a profound effect on the manufacture of wrought iron, which to-day has shrunk to a very small proportion of its former size.

In the transitional stage from wrought iron to steel, South Staffordshire has played an important part in the evolution and development of the two steel-making processes. Sir William Siemens was steadily perfecting his process, and he built his first successful open-hearth furnace in Birmingham in 1866, when he succeeded in making good steel from old rails.

One of the early Bessemer plants to be operated was established at the works of Messrs. Lloyd, Foster & Co., Wednesbury, now the Patent Shaft & Axletree Co., Ltd. This firm can also claim to be one of the first to establish a basic open-hearth plant and has continued to develop the open-hearth process since its inception.

My father, the late Lord Dudley, erected a basic open-hearth furnace in 1889 at Round Oak Works, and I believe I am correct in saying that Mr. Benjamin Talbot, the inventor of the process which bears his name and a Past-President of this Institute, carried out some of his early experimental work in this furnace.

The work of these pioneers should serve as an inspiration to the younger men engaged in the industry and encourage them to pursue the study of the fundamental principles of metallurgy and chemistry, so that still further development in the iron and steel industry may take place for the lasting good of this country and the world in general.

As President of the British Cast Iron Research Association I have recently advocated the expenditure of a considerable sum per annum on comprehensive research work, as I am convinced that without this necessary work our industry would be seriously handicapped.

When one tries to look ahead into the future of iron and steel-making one wonders whether we are moving in the right direction, and whether all that we are trying to do is in the best interests of the industry and the nation.

This being a free country, we are all born individualists, and as such we are slow to conform to control, rules and regulations. We have always enjoyed freedom of action and freedom in our trading and it has served us very well. But in the post-war years we have experienced within our industry a measure of co-operation and collaboration, both national and international, such as our ancestors would never have dreamed of. I, for one, firmly believe that this is all for the good. We have voluntarily surrendered some of our individualistic habits without sacrificing our individual genius.

By doing so we have developed our industry along the most reasonable and economic lines, and I believe that there is scope for a still further strengthening, and indeed expansion of this spirit for our own benefit and for the lasting good of the nation.

To my mind there are two definite and distinct reasons for close national co-operation. The first and most important is that in time of national emergency our safety depends largely upon our ability to produce the iron and steel necessary to meet national danger. The second reason is that if we are going to maintain our commercial position in the world's markets, we must be equipped with the most up-to-date plant for ensuring the maximum efficiency, and only by such means can the nation continue to enjoy the high standard of living that we have attained compared with all other nations.

International collaboration is an equally essential factor in the prosperity of our industry. There is a tendency—and I think it is a natural and proper tendency—each to give preference in his own

thoughts to the welfare of the industry of his own country, but if we take a wider view our national prosperity is ultimately dependent on that of others. The world is an economic as well as a physical unit. We, in the steel industry, have done our best to co-ordinate our activities on an international basis and we think that the arrangements we have made compare favourably with those of other industries. They embrace all the leading producing countries in Europe and are not confined to Europe. I think they should ultimately include the industry of the world. The maintenance of these agreements is bound occasionally to cause difficulty; I hope, however, that as and when difficulties arise we shall, all of us, whatever the country to which we owe allegiance, endeavour to reach a solution that may be acceptable to our colleagues as well as to ourselves.

The international Membership is one of the greatest assets of our Institute and its international composition is one of the greatest services which it renders to our industry. Technical progress, which we endeavour to foster, and the spread of scientific knowledge which it is our duty to encourage, know no national boundaries. We are always glad when Members from other countries do us the honour of visiting us here in London, and I welcome most heartily those of our friends from the Continent, from America and from other parts of the world, whom I see here to-day. I hope that when we visit Canada and the United States of America in the autumn many of our Members from other countries will travel with us. That may afford a useful opportunity of demonstrating and consolidating the international friendships by which our industry is united.

I have mentioned that the modern iron industry of South Staffordshire is well over 300 years old; for at least half that period it has been impossible to consider its development and fortunes apart from those of the rest of Great Britain. Similarly, although our national preoccupations must at the moment be great, it is foolish to attempt to assess the prosperity and progress of the British Steel Industry apart from that of the rest of the world. It will remain a major function of the Iron and Steel Institute to unite in our discussions impartially the views of all nations.

We are entering upon a new phase in the history of iron and steel making; with all other nations developing their natural resources to the utmost self-sufficiency and with our Dominions and overseas possessions increasing their steelmaking potentialities, it is imperative that we should have the most efficient plant in the world. Germany has greatly added to her steelmaking strength by the acquisition of Austria, in addition to which she is now erecting a large steelmaking plant in the Salzgitter district, which, together with plant to be erected later in Linz and Baden, will, I am informed, have an ingot capacity of about 6 million tons per annum, and will operate largely on native ores, which are of a low grade. This

additional output will make Germany easily the second largest producing country in the world, with a capacity of approximately 25 million tons per annum. Russia, also, is rapidly extending, and sooner or later her products will find their way into the world's

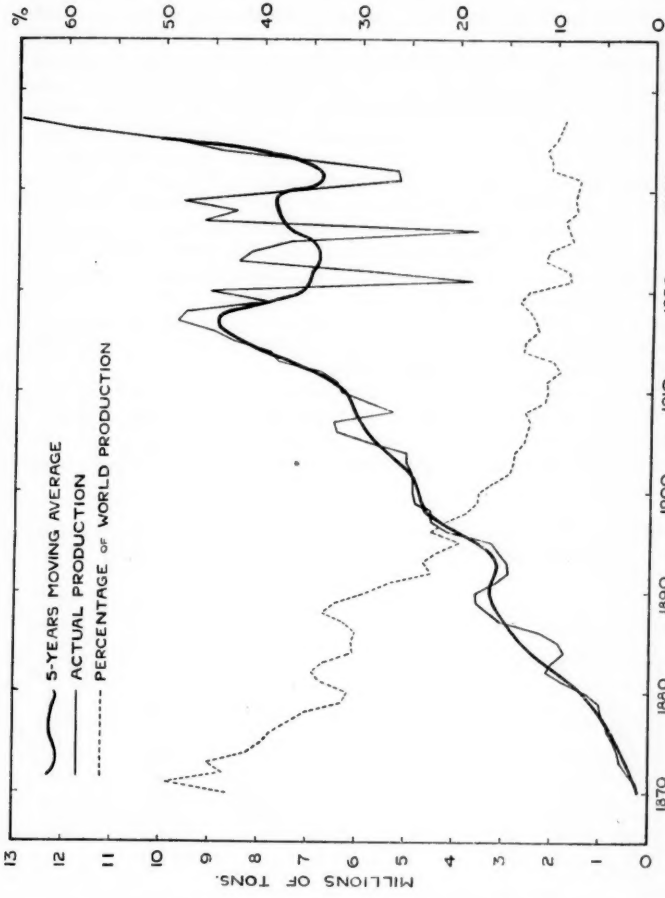

FIG. 1.—Production of Steel in Great Britain.

markets. In 1937, she produced over 17½ million tons of steel. Other countries, too, are entering the steelmaking field, and those already manufacturing steel are increasing their production, with

the result that in the year 1937 the world's production of steel was 133,310,000 tons.

Even with these developments of steelmaking in all parts of the world, Great Britain, as shown in Fig. 1, has well maintained her proportion of the world output over the past twenty-five years. Up till the Great War, production in this country was increasing each year at a comparatively steady rate, but it must be borne in mind that over this period the use of steel was being substituted for that of wrought iron, and this fact helped to make the growth of steel production more uniformly progressive than in the post-war years.

The chart shows the exceptional wartime expansion of production, followed by the post-war depression in trade, which owing to our fiscal and monetary policy bore particularly heavily on this country. In spite, however, of the vicissitudes which the steel trade has experienced, the underlying trend of production has been upwards ; and I think it can fairly safely be forecast that this trend will continue, so that by 1948–50 Great Britain should be producing some 15 million tons of steel a year. In making this forecast I have regard not only to the growing economic strength and development of the country, but also to the large number of new uses to which steel is being put at the present time.

This country is, of course, particularly well endowed for steel production with its abundant coal supplies, but in addition to this it is able to supply a larger proportion of its ore requirements than many other important steelmaking countries, as will be seen from Table I.

TABLE I.—*Production of Steel and of Iron Ore, and Imports of Iron Ore into the Chief Steel Producing Countries in* 1936.

Country.	Steel Production.	Ore Production.	Imports of Iron Ore.
	Thousands of Tons of 2,240 lb.		
United Kingdom	11,780	12,701	5,960
Germany	18,900	6,548	18,178
France	6,600	32,689	385
Belgium and Luxemburg...	5,080	4,820	10,549
Italy	1,990	812	40
Czechoslovakia	1,540	1,082	546
Poland	1,110	461	340
United States	47,770	48,618	2,232
Russia	16,080	27,477	...
Japan	5,000	1,500*	3,768
India	940	2,558	...
Australia	750	1,890	...

* Provisional.

We are blessed with wonderful natural resources, and we must develop them at the right time and on the right lines. We have

large deposits of low-grade ores still largely unworked, particularly in the Banbury and Oxford districts, which some day will prove to be of great value to the nation. They are adjacent to the South Staffordshire area, which, although it no longer retains the pride of place as an iron and steel producing area, is still one of, if not the largest iron and steel consuming district in Great Britain. We have no carefully recorded statistics of iron and steel consumption in the various districts, but in the South Staffordshire area in 1936 around 800,000 tons of steel billets and slabs were, I believe, used ; in addition, many thousands of tons of steel joists, sections, plates and sheets were consumed, and this heavy consumption continues to grow each year. So I look forward with confidence to the future prosperity of our great industry, which is so essential to the well-being and safety of the nation, and I take courage for the future when I see the support that is given to this Institute and the interest that it commands from all the important iron and steel makers in the country.

AN EXPERIMENTAL ENQUIRY INTO THE INTERACTIONS OF GASES AND ORE IN THE BLAST-FURNACE.

PART V.—THE INFLUENCES OF HYDROGEN AND STEAM AT 450–850° C.[1]

By WILLIAM A. BONE, D.Sc., F.R.S., H. L. SAUNDERS, Ph.D., and H. J. TRESS, Ph.D. (Bone Research Association, Ltd., London).

Summary.

The two main reactions occurring in the blast-furnace are (1) the catalytic decomposition of carbonic oxide, $2CO \longrightarrow C + CO_2$, at *circa* 450° C. resulting in the deposition of carbon within and around the ore, and (2) the reduction of the oxides of iron, $Fe_xO_y + CO \longrightarrow Fe_xO_{y-1} + CO_2$, at higher temperatures. Data have been given in previous communications of the relative velocities of these reactions under varying conditions of temperature, CO_2 concentration, speed of gas flow, and degree of reduction of the ore, referred in all cases to a state of $CaCl_2$-dryness in the gas phase. Relative velocity measurements have now been extended to include the effects produced by additions of up to 2% of hydrogen and steam to blast-furnace gas over a temperature range of 450° to 850° C. The results show that both hydrogen and steam accelerate carbon deposition. Hydrogen also accelerates ore reduction, whilst the influence of steam is less definite.

In Part IV.[2] of this series of papers an experimental method was described for the determination of the relative velocities of carbon deposition and ore reduction under conditions comparable with those prevailing in the blast-furnace as regards temperature, composition of the gases and their speeds of flow over the ore, for all stages in the reduction process up to some 80% of the total possible oxygen removal. The results of the measurements were summarised in a series of graphs and covered the useful limits of the variables. No attempt was made to deal with any more complex system than one containing Fe, Fe_xO_y, CO, CO_2 and nitrogen in a state of $CaCl_2$-dryness, although at some stages of the reaction carbon might be present either in the free state or as iron carbide or carbonyl.

As, however, blast-furnace gas normally contains small percentages of hydrogen and steam it was thought desirable to investigate their specific influences upon the principal reactions involved,

[1] Received February 25, 1938.

[2] *Journal of the Iron and Steel Institute*, 1934, No. I., p. 47.

with special reference to the previously observed trough in the rate of ore reduction between 700° and 800° C., so as to ascertain whether or not it still persists in the presence of hydrogen-containing constituents.

This further work may be divided into two sections, namely, the influences of hydrogen and steam, respectively, (1) on the carbon deposition by the reversible $2CO \rightleftharpoons C + CO_2$ reaction at 450° C., and (2) on the ore reduction over a temperature range of 650° to 850° C.

With regard to (1) it may be recalled that, whereas at 450° C. the continued passage of dry and hydrogen-free B.F. gas [1] over an anhydrous hematite ore after the $Fe_2O_3 \rightarrow Fe_3O_4$ ore-reduction stage has been passed results in carbon deposition exclusively, through the catalysed $2CO \rightarrow C + CO_2$ reaction, both carbon deposition and ore reduction proceed simultaneously at 650° C. under favourable conditions; and although the latter predominates until most of the oxygen has been removed from the ore, the appropriation of the carbonic oxide as between the two reactions at any instant depends not only upon the state of deoxidation of the ore, but also upon the CO/CO_2 ratio and the amount of deposited carbon already present.

Moreover, in regard to (2) it has been shown that, with a $CaCl_2$-dried system, instead of the relative velocities of the ore reduction $Fe_xO_y + CO \rightarrow Fe_xO_{y-1} + CO_2$ reaction continuously increasing with temperature between 650° and 1000°, under corresponding conditions as regards gas speeds, CO_2 percentages and degrees of ore reduction, there is a decided minimum velocity in the region of 750° throughout the last two-thirds of the oxygen removal. It was suggested that the explanation of such an unexpected feature of the phenomena might be found in some change in the mechanism of the reaction in the neighbourhood of 750°, *e.g.*, its occurrence through the intermediary of a carbide instead of a carbonyl of iron. But whatever the explanation may be, it seemed important to determine by further experimental investigation whether or not (and, if so, then to what extent) such feature is affected by the presence of hydrogen or steam in the system.

(1) *Apparatus.*

In order to ensure reliability of the results under the new experimental conditions, the apparatus, Fig. 1, previously employed (*vide* pp. 69–76 of Part II. of this series [2]) was modified in certain particulars. A five-sectioned, individually controlled "concordin"-wound electric furnace remained the source of heat, sections *D'*, *E'*

[1] "B.F. gas" is used to indicate a synthetic blast-furnace gas, the initial composition of which is 33·3% of carbonic oxide and 66·7% of nitrogen by volume.

[2] *Journal of the Iron and Steel Institute*, 1930, No. I.

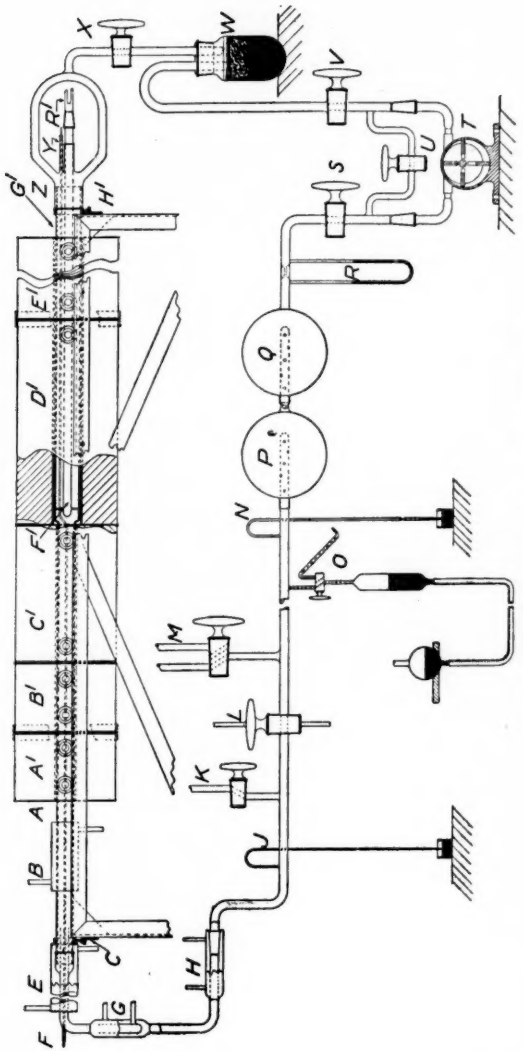

FIG. 1.—High-Velocity Circulation Apparatus.

and F' forming the preheater for the entering gases. The charge of ore was normally contained within section C', whilst sections A' and B' formed a lagging to minimise end radiation losses. The gases were circulated in the closed system by a Wade rotary blower, T', which had a capacity of 120 cu. ft. per min. A special vacuum-tight water-cooled gland was fitted to the shaft, whilst the rotor and motor armature were mounted in ball races; at full speed the unit was practically vibrationless. The bearings were packed with "vacuum" grease, and suitably arranged flanges on the rotor prevented contact of the circulating gas stream with the lubricant.

Adequate preheating of the gases was obtained by a suitable regulation of the current in D', E' and F', and the temperature of the gases at the upstream end was checked by means of an adjustable Pt/Pt–Rh thermocouple, contained within a quartz sheath, at a point about 40 cm. in advance of the charge of ore. The previous arrangement of the sheath through the centre of the ore was found to be impracticable at high temperatures, owing to the danger of fluxing and restriction of the gas flow. For the same reason the ore was contained within a pythagoras tube, 1 in. in dia., extending to the water-cooled joint inside the cooler E. The ore was kept in position by two grids of alundum, one resting against a collar in the pythagoras tube and the other cemented in position after inserting the charge of ore.

Additional cooling was found to be desirable to keep the joints at the downstream end intact, and this was accomplished by an internal tubular cooler built up entirely of fused quartz and placed in position at BA but *inside* the pythagoras tube, the entry and exit of the feed water being carried through the cap F, together with a second thermocouple sheath extending as far as the charge of ore. It was thus possible to ascertain at any moment the temperature of the gases reaching and leaving the ore, and the maximum gradient even at 850° C. was never more than 7° C. Provision was made for filling and evacuating the system at M and K, also for taking gas samples at O. Pressure measurements were made at J and N, and the speed of gas flow was taken at R. Capacity bulbs at P and Q served to adjust the volume of gas relative to the weight of ore used.

Great care was necessary to prevent any condensation of moisture from the system when using gases nearly saturated with water vapour at room temperature. Hence the whole of the apparatus was mounted on a slate bench heated from below by three hot-water radiators so that the average temperature of all the component parts was several degrees higher than that of the air of the laboratory; the same was also the case with all feed water to the condensers and drip feeds.

The reaction tube was also provided with a by-pass extending from the tap X to a T-piece situated between H and J, and differential manometers were attached at points J and N.

(2) *Procedure.*

The experimental procedure was briefly as follows: A weighed quantity of ore *A*, taken from the same bulk sample that was set aside for the whole of this section of the investigation, was charged as indicated above and the apparatus assembled. After heating the ore in a current of dry air at 650° C., the whole system was thoroughly evacuated by means of two hyvac pumps. The temperature of the various sections of the furnace was then adjusted to the required degree and the apparatus (excluding the reaction tube) filled with B.F. gas; all gaseous mixtures were separately made up from their constituents before each experiment and circulated *via* the by-pass for 45 min. to ensure thorough mixing. In those cases where steam was initially present the gases were introduced through constant-temperature humidifiers to give the required moisture content. When all was ready for the commencement of an experiment the taps *X* and *L* were opened and simultaneously the circulating pump was started. The preheater current was adjusted as necessary to keep the temperature of the entering gases (as indicated by the first thermocouple) at the experimental temperature whilst still in advance of the ore. Samples of gas were withdrawn at suitable intervals *via O* and pressure observations taken, so that the progress of the reactions could be studied from the analytical data thus obtained.

The whole of the work was carried out on a comparative basis in order to avoid as far as possible differences in the physical state of the ore used in the numerous groups of experiments from which the data were ultimately deduced. In Part II.[1] of this series of papers mention was made of the observed strong affinity for moisture of systems containing partially reduced oxides of iron and deposited carbon even at temperatures as high as 750°; such moisture was apparently adsorbed, and was given up again on raising the temperature above 850° C. The quantities so adsorbed have since been shown to depend upon a number of factors, *e.g.*, temperature, time of contact and gas composition. Thus at the outset the necessity arose for accurately standardising the experimental conditions so that any predetermined physical state of the ore could be reproduced at will no matter what treatment it had undergone between the successive experiments. All attempts at control by change of temperature were abortive, because it was found that such alteration always produced some change in the permeability of the ore to the reacting gases, with consequent alteration in the reaction velocities under investigation.

In preliminary experiments a fresh charge of ore was employed for each measurement, but this proved unnecessary, for it was ascertained that the charge could be dried out satisfactorily at any selected temperature by circulating P_2O_5- or $CaCl_2$-dried nitrogen

[1] *Journal of the Iron and Steel Institute*, 1930, No. I., p. 35.

over it, provided that oxides of carbon were excluded, the adsorbtion of moisture being in some way connected with the water-gas reaction, the ore surface acting as a catalyst. Hence, after carrying out an experiment with hydrogen or steam in the gaseous phase, it was always possible not only to dry out the solid phase by such treatment, and so produce a state of "$CaCl_2$-dryness" in the system whenever necessary, but also to prove its re-attainment by showing the reaction velocities to be identical with those previously determined.

By thus alternating the experiments in any series between the "wet" and "dry" states, not only were reliable comparative figures for the reaction velocities obtainable under all conditions, but differences due to changes in the physical state of the ore could be eliminated.

Such then was the procedure adopted throughout the present investigation; the hematite *A* (Fe_2O_3 82·36%, CaO 0·9%, SiO_2 14·63%, Al_2O_3 0·23%) was again employed as the standard ore, and all measurements were at a medium speed of gas flow (16 ft. per sec. at the ore surface).

(3) *Relative Influences of Hydrogen and Steam upon Carbon Deposition at 450° C.*

At 450° C. ore-reduction velocity measurements were out of the question, because so soon as reduction had passed beyond the $Fe_2O_3 \rightarrow Fe_3O_4$ stage the catalytic decomposition of carbonic oxide

TABLE I.—*Influence of Additions of Hydrogen upon Carbon Deposition at 450° C.*

Time of Contact. Sec.	Hydrogen Added.						
	Nil. $CaCl_2$-dry.	½%.	¼%.	¾%.	1%.	2%.	4%.
0·21	5·75	11	12·5	13·5	15	16·7	18
0·42	11·5	22	25	28	29	31	33
0·63	17·25	33	37·5	42	42	42·5	44
0·84	23·25	42	45·5	48	51	51·7	53
1·04	28·5	50	53	56	57	58	59
1·25	34	57	59·2	62	64	64·5	65
1·46	38·5	63	64	67	67·5	69	69·5
1·67	42·5	67	69·2	71	72·5	72·5	73
1·88	47	73	73·5	74	74	74·5	75
2·08	51	75	75	75·5	76	76	76
2·29	54·5	76	76	76	76	76	76
2·50	58	...	...	...	...	...	...
2·92	64	...	...	...	...	...	...
3·13	66	...	...	...	...	...	...
3·55	69	...	...	...	...	...	...
3·96	70·5	...	...	...	...	...	...
4·18	70·7	...	...	...	...	...	...

TABLE II.—*Influence of Additions of Steam upon Carbon Deposition at 450° C.*

Time of Contact. Sec.	Steam Added.				
	Nil. $CaCl_2$-dry.	¼%.	½%.	1%.	2%.
0·21	5·75	6·5	9	11·5	15
0·42	11·5	16·5	18·5	24	28
0·63	17·25	26	28	34	38·25
0·84	23·25	34·5	37	42	46·5
1·04	28·5	42·25	44·5	50	53
1·25	34	49	51·5	55·5	57·75
1·46	38·5	55	57·5	60·75	63
1·67	42·5	60·25	62	64·5	66·25
1·88	47	64·25	66	67	68·5
2·08	51	68·5	69·5	70	70·5
2·29	54·5	71	71·5	71	71·5
2·50	58	...	...	...	...
2·92	64	...	...	...	...
3·13	66	...	...	...	...
3·96	70·5	...	...	...	...
4·18	70·7	...	...	...	...

predominated almost exclusively, resulting in both carbon impregnation within the interstices of the ore and its deposition on the ore surface, and as reaction proceeded in a closed system according to the equation $2CO \rightleftharpoons C + CO_2$, its velocity was deduced from pressure readings, checked by gas analyses, at suitable time intervals. The data so obtained have been summarised in Tables I. and II. and Figs. 2 and 3, in which the carbon deposited through the reaction $2CO \rightarrow C + CO_2$ has been plotted against the time of contact in seconds. The upper six curves show the rate of carbon deposition when ⅓%, ½%, ¾%, 1%, 2% and 4%, respectively, of hydrogen had been added to the dry B.F. gas, as compared with that shown in the lowest curve for a $CaCl_2$-dry state, which was reproduced between each successive "wet" experiment; usually two or three intermediate circulations with $CaCl_2$-dry nitrogen were necessary before arriving at the true "dry" velocity curve. Typical curves obtained during the drying out process in the intermediate circulations are shown at *a*, *b* and *c*, Fig. 2.

It will be seen that the addition of as little as 0·33% of hydrogen resulted in a marked increase in the velocity of carbon deposition, equilibrium being reached in about a third of the usual time required for the dry system; for shorter times of contact and low CO_2 contents in the gas the increase in reaction velocity was even more pronounced. Increasing the hydrogen content to 0·5% did not result, however, in a corresponding further increase in the reaction velocity; indeed, for successive hydrogen increments in the gases

the corresponding increases in the reaction velocity became progressively less marked, until, with more than 1% of hydrogen, a

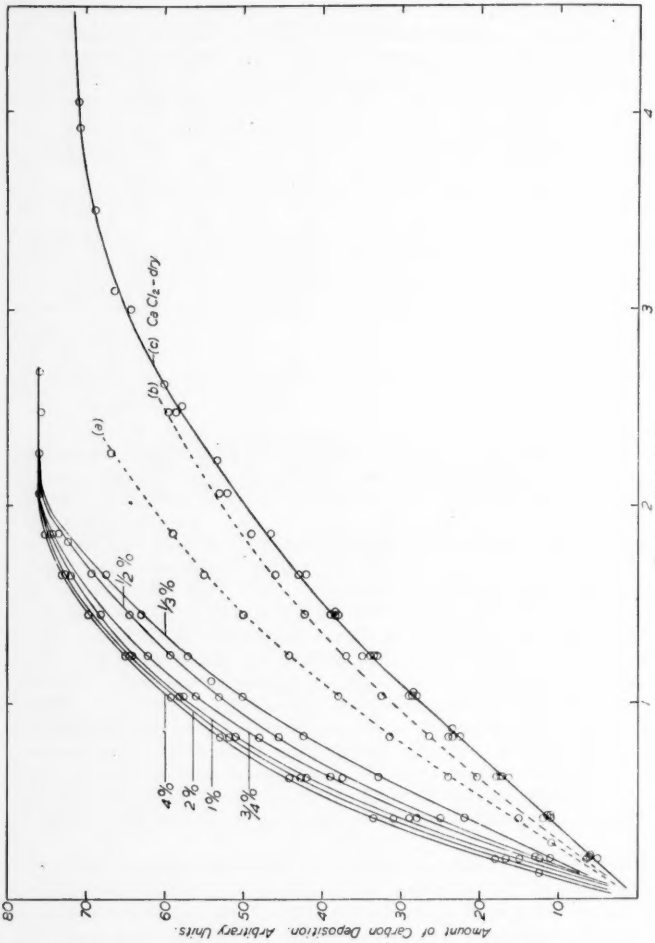

FIG. 2.—Influence of Additions of ¼%, ½%, ¾%, 1%, 2% and 4% of Hydrogen upon Carbon Deposition.

limit to its influence was being approached. It should be noted that the time required (slightly over 2 sec.) for the attainment of equilibrium in the catalysed $2CO \rightleftharpoons C + CO_2$ system was almost

independent of its hydrogen content. Moreover, it will be seen from the curves that, between the limits studied, the greatest

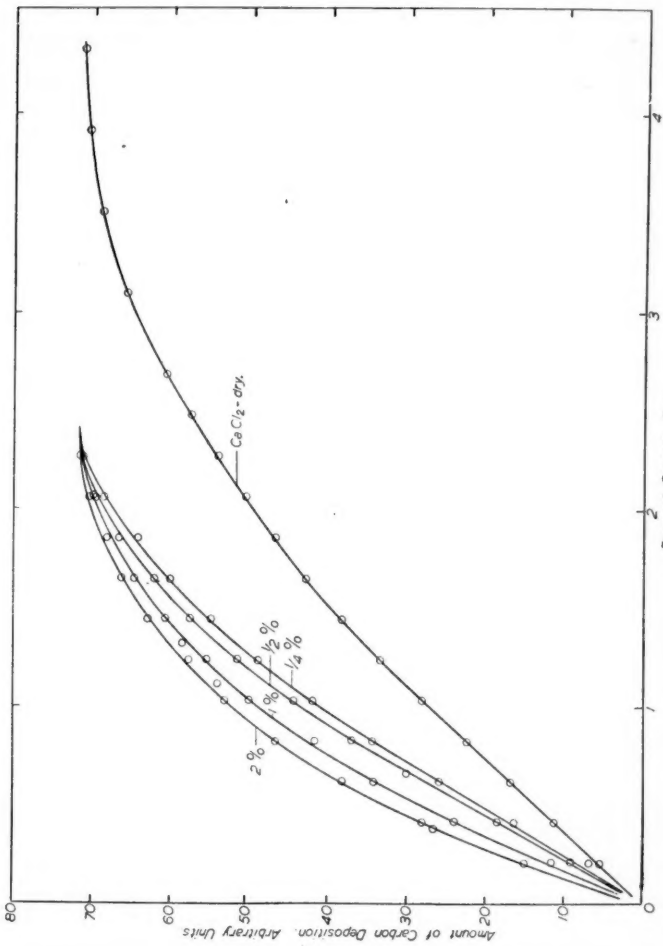

FIG. 3.—Influence of Additions of ¼%, ½%, 1% and 2% of Steam upon Carbon Deposition.

divergence between the effects of successive hydrogen increments was most pronounced when the time of contact was about 1 sec. and the CO_2 concentration about 12%.

FIG. 2.—Influence of Additions of ¼%, ½%, 1%, 2% and 4% of Hydrogen upon Carbon Deposition.

From Fig. 3 it will be seen that similar results followed successive additions of steam to the system, though the time required for the attainment of equilibrium was slightly longer and the effects of corresponding increases of steam were relatively smaller than with hydrogen, although the divergence range was again greater after a contact time of 1 sec.

Such observed changes in reaction velocity can only be ascribed to " catalysis," because a careful examination of the carbon-impregnated and carbon-deposited ore never showed any physical or chemical difference other than a slight increase in the degree of reduction in experiments in which hydrogen had been added to the dry system, or a slight oxidation with steam additions. Moreover, the rate of disappearance of hydrogen or steam from the systems, respectively, was comparatively slow as compared with the rate of approach to the CO/CO_2 equilibrium ratio of 0·3.

(4) *Relative Influences of Hydrogen and Steam upon Ore Reduction.*

(i) **At 650° C.**—Whereas at 650° the reduction of the ore with a $CaCl_2$-dried B.F. gas and a low gas velocity at the ore surface normally proceeds without carbon deposition until most of the oxygen has been removed from the ore, the reaction becomes more complicated when small quantities of hydrogen or steam are present in the system. It had already been shown in Part IV.[1] of this series how an increase in gas velocity widens the temperature range of carbon deposition; and it now appears that the same effect likewise results from the presence of hydrogen or steam in the system, for it has been found that, in the presence of hydrogen or steam at 650°, both ore reduction and carbon deposition occur simultaneously as soon as the ore has been about 50% reduced. The proportionate appropriation of carbonic oxide for the latter reaction steadily increases as the deoxidation of the ore proceeds beyond that point, and although it would still be possible to obtain a nearly 100% ore reduction in the presence of hydrogen, the ore would then contain a far greater quantity of carbon than when $CaCl_2$-dried B.F. gas is used alone. On using wet B.F. gas, however, a considerably lower reduction limit is imposed, and in fact the continued passage of such a gas over the solid charge results in an *oxidation* of the ore with increasing carbon accumulation. Some of the carbon so liberated enters into combination with the iron as carbide, although the ratio of free to combined carbon is by no means constant.

The experimental results are summarised in Tables III. and IV. and in the curves of Fig. 4 for typical systems containing 2% of hydrogen and steam, respectively, and CO_2 contents of 2·5, 5·0 and 7·5%, respectively, throughout the greater part of the ore reduction. In each case the relative ore-reduction velocities for the gases containing 2% of hydrogen and steam, respectively, referred always

[1] *Journal of the Iron and Steel Institute*, 1934, No. I., p. 47.

TABLE III.—*Comparative Velocities in the Presence of Hydrogen.* 650° *C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
10	2·02	1·62	1·26
15	1·97	1·6	1·24
20	1·86	1·61	1·33
25	1·74	1·49	1·43
30	1·59	1·42	1·52
35	1·47	1·41	1·54
40	1·5	1·44	1·54
45	1·5	1·44	1·5
50	1·5	1·48	1·5
55	1·52	1·44	1·56
60	1·54	1·57	1·84
65	1·54	1·69	2·17
70	1·58	1·74	...
75	1·63	...	...

TABLE IV.—*Comparative Velocities in the Presence of Steam.* 650° *C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
10	1·09	1·20	...
15	1·06	1·27	1·16
20	1·15	1·26	1·16
25	1·21	1·21	0·94
30	1·25	1·17	0·91
35	1·26	1·15	0·90
40	1·27	1·12	0·88
45	1·28	1·12	0·88
50	1·29	1·10	0·87
55	1·26	1·09	0·93
60	1·26	1·02	0·9
65	1·23	0·96	0·85
70	1·10	0·92	0·7
75	1·17	...	...

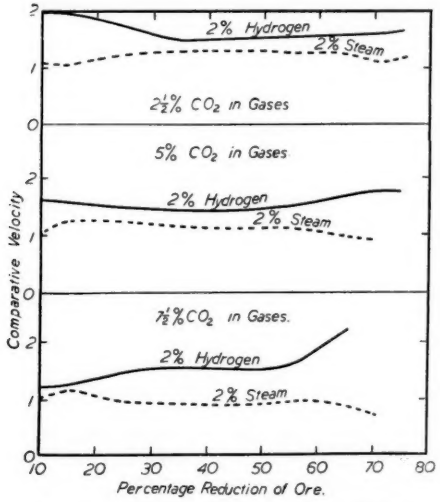

FIG. 4.—Comparative Velocities at 650° C.

to the corresponding velocity for the $CaCl_2$-dried system as unity, are plotted as ordinates against the degrees of ore reduction (abscissæ in the curves) for the three CO_2 concentrations referred to.

It will be seen that the addition of 2% of hydrogen to the $CaCl_2$-

dried reactants materially increased the rate of ore reduction. For the 30 to 55% ore-reduction range, the increase was uniformly about 50% and practically independent of the CO_2 concentration in the system (*vide* the data within the rectangle in Table III. and the flat portion of the corresponding curves in Fig. 4). There were characteristic breaks in the curves at about 30–35% ore reduction, corresponding to the transition from Fe_3O_4 to FeO in the solid phase. Another interesting feature was the progressive rise in the relative velocity rates after the 55% ore-reduction stage had been passed, this being the more marked as the CO_2 content of the gas phase increased. Indeed it would seem that as the appropriation of the initial carbonic oxide for ore reduction diminishes towards zero, oxygen may continue to be removed from the ore by the hydrogen present.

Some evidence was forthcoming of the presence of hydrogen favouring carbide formation when the ore is highly reduced, but this is a matter needing further investigation and its discussion is deferred until a subsequent communication.

It will be seen that the influence of steam upon the ore-reduction velocity at 650° (Table IV.) might be accelerative or otherwise according to the degree of ore reduction and the CO_2 content of the gas phase. With a 2·5% CO_2 content, it was always accelerative, though never so highly as was the influence of hydrogen; but with a 7·5% CO_2 content, its effect was retarding throughout most of the ore-reduction range.

(ii) **At 750° C.**—Before reaching 750° in the blast-furnace the ore has already passed through a zone (*circa* 450°) of carbon impregnation and deposition, and, seeing that in the region of 700° interaction between impregnated carbon and Fe_xO_y comes into play, the removal of oxygen might conceivably be even greater by such carbon than by carbonic oxide in the furnace gases—hence the importance of ascertaining whether the previously observed temperature zone of minimum ore-reduction velocity is modified in any way by the presence of hydrogen or steam in the system.

The results obtained at 750° are summarised in Tables V. and VI. and in the curves of Fig. 5 on precisely the same basis as those obtained at 650°. Again it was found that, whereas hydrogen always materially accelerated the ore reduction, the influence of steam was usually much smaller and might even be slightly retarding. Moreover, at this temperature any marked continuous rise in the hydrogen curve after passing the 50% ore-reduction stage was restricted to systems with a CO_2 content of 7·5%.

(iii) **At 850° C.**—Seeing that, whereas below 850° carbonic oxide is a more effective reducing agent than hydrogen as regards Fe_xO_y, the reverse is the case at higher temperatures (*vide* Part IV., p. 64), it might be expected that, *ceteris paribus*, any accelerative influence of hydrogen upon the rate of ore reduction observed at lower temperatures would, in general, be more marked at 850°. A

TABLE V.—*Comparative Velocities in the Presence of Hydrogen. 750° C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
15	...	1·15	1·3
20	1·25	1·1	1·46
25	1·3	1·0	1·36
30	1·48	1·08	1·26
35	1·48	1·17	1·27
40	1·44	1·32	1·22
45	1·41	1·41	1·29
50	1·45	1·48	1·39
55	1·47	1·55	1·53
60	1·55	1·65	1·6
65	1·49	1·65	1·56
70	1·4	1·47	1·82
75	1·21	1·4	...
80	1·3	1·33	...

TABLE VI.—*Comparative Velocities in the Presence of Steam. 750° C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
15	...	1·1	1·0
20	1·0	1·05	0·9
25	1·0	1·0	0·87
30	1·0	1·02	0·82
35	1·0	1·14	0·84
40	0·93	1·20	0·9
45	0·93	1·31	0·98
50	0·9	1·35	1·21
55	0·9	1·32	1·22
60	0·9	1·38	1·25
65	0·91	1·31	1·32
70	0·96	1·26	1·46
75	1·0	1·17	...
80	0·9	...	...

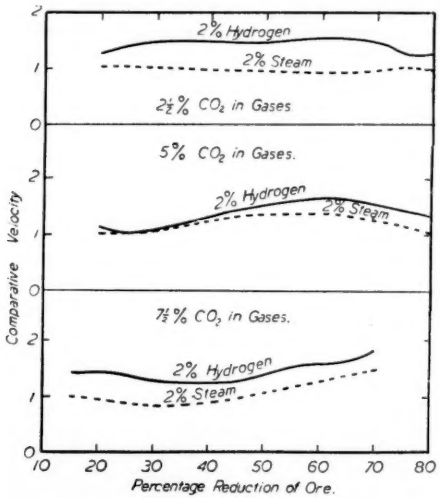

FIG. 5.—Comparative Velocities at 750° C.

comparison of the results summarised in Table VII. and the curves of Fig. 6 with those of the corresponding experiments at lower temperatures will show that, although such was always found to be so throughout practically the whole ore-reduction range for systems

TABLE VII.—*Comparative Velocities in the Presence of Hydrogen. 850° C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
10	1·55	1·5	1·38
15	1·6	1·75	1·4
20	1·66	1·65	1·46
25	1·62	1·60	1·43
30	1·68	1·33	1·56
35	1·78	1·4	1·7
40	1·82	1·33	1·72
45	1·83	1·36	1·62
50	1·76	1·33	1·69
55	1·74	1·3	1·62
60	1·78	1·27	1·53
65	1·82	1·33	1·62
70	1·9	1·38	1·74
75	2·0	1·45	2·0
80	2·4	2·0	2·2

TABLE VIII.—*Comparative Velocities in the Presence of Steam. 850° C.*

Percentage Reduction.	2½% CO_2.	5% CO_2.	7½% CO_2.
10	1·13	0·9	1·10
15	1·15	1·0	1·10
20	1·16	1·13	1·27
25	1·16	1·32	1·43
30	1·2	1·39	1·38
35	1·21	1·38	1·42
40	1·18	1·35	1·46
45	1·14	1·23	1·28
50	1·04	1·09	1·15
55	1·0	1·0	1·10
60	0·96	0·85	1·0
65	0·91	0·75	0·87
70	0·85	0·64	0·87
75	0·67	0·55	0·75
80	0·5	0·44	...

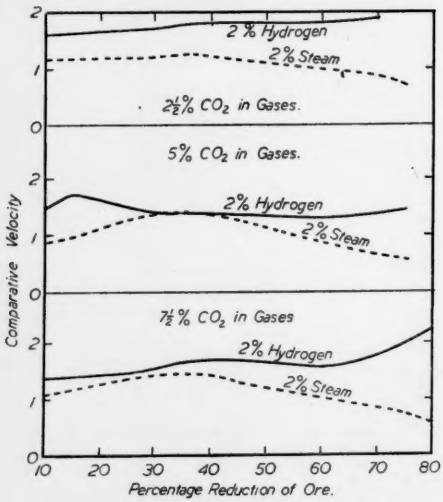

FIG. 6.—Comparative Velocities at 850° C.

containing 2·5 or 7·5% of carbon dioxide, it was not invariably so with intermediate CO_2 contents, for some reason or other not yet apparent. Nevertheless, at 850° the addition of 2% hydrogen

to the $CaCl_2$-dried system invariably accelerated the ore reduction in a marked degree, and especially so during the penultimate stage of the process. On the other hand, the same addition of steam (Table VIII. and Fig. 6), although accelerating the earlier, definitely retarded the later stage of ore reduction, irrespective of the CO_2 content of the system. The latter circumstance is doubtless due, in part at least, to some transference of oxygen from the gaseous to the solid phase (*i.e.*, oxidation of sponge iron or its lower oxides by steam), although the reducing potential of the carbonic oxide present was always sufficiently high to ensure a resultant positive reduction velocity in the system as a whole up to some 80% of the total deoxidation, even when as much as 7·5% of carbon dioxide was present in the gas phase.

The 80 to 100% ore-reduction range requires further detailed investigation, however, before any conclusion regarding it can be established with certainty, although, from the general character of the curves so far obtained, it seems likely that a lower reduction limit will be imposed on systems in which the H_2O/H_2 ratio is higher than under a condition of $CaCl_2$-dryness.

(5) *The Trough of Depression in the Ore-Reduction Velocity at* circa *750° C.*

Analyses of the experimental results have enabled a series of comparative curves (Table IX. and Figs. 7, 8 and 9) to be deduced,

TABLE IX.—*Relative Velocities at* 50% *Reduction.*

	2½% CO_2.			5% CO_2.			7½% CO_2.		
Temperature:	650° C.	750° C.	850° C.	650° C.	750° C.	850° C.	650° C.	750° C.	850° C.
$CaCl_2$-dry . .	3·50	1·40	2·00	2·60	0·95	1·30	1·30	0·80	0·80
2% Hydrogen .	5·25	2·03	3·52	3·85	1·40	1·70	1·95	1·11	1·35
2% Steam . .	4·52	1·26	2·08	2·86	1·28	1·42	1·13	0·97	0·92

showing the influence of 2% of hydrogen and steam, respectively, upon the relative velocities of ore reduction over the whole 650–850° temperature range for the 50% ore-reduction stage and CO_2 contents of 2·5%, 5·0% and 7·5% in the gas phase, the relative ore-reduction velocities, expressed in arbitrary units, being plotted as ordinates against temperatures as abscissæ. From these it will be seen that, although, in general, both hydrogen and steam, but especially the former, favourably influence the velocity of ore reduction, they do not eliminate the trough of depression in it at *circa* 750°. It would further appear that as the CO_2 content of the gas phase rises, not only does the velocity of ore reduction decrease but the depth of the trough of depression at 750° does so also.

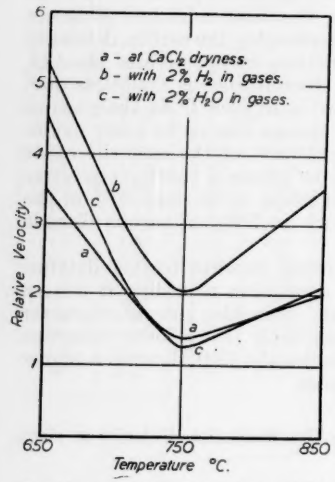

FIG. 7.—Relative Velocities; 2½% of CO_2 in the Gases.

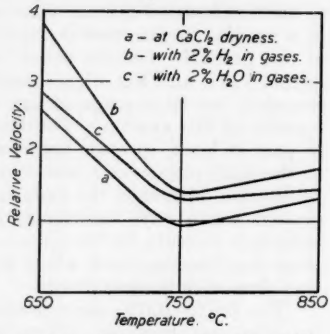

FIG. 8.—Relative Velocities; 5% of CO_2 in the Gases.

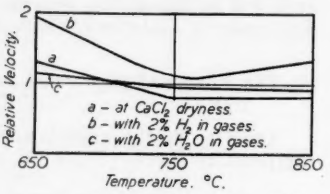

FIG. 9.—Relative Velocities; 7½% of CO_2 in the Gases.

(6) *Summary.*

The influences of small percentages of hydrogen and steam, respectively, upon (1) carbon deposition by the reversible $2CO \rightleftharpoons C + CO_2$ reaction at 450° and upwards, and (2) ore reduction through the interactions of blast-furnace gas and Fe_xO_y have been experimentally studied over a wide range of ore reduction, and the following conclusions have been established.

(1) Additions of 0·25%, 0·5%, 1·0% and 2·0% of either hydrogen or steam to a $CaCl_2$-dried "blast-furnace gas system" materially increase the rate of carbon deposition at 450°, the effect being more pronounced with hydrogen than with steam. In either case, however, a limit is being rapidly approached as the hydrogen or steam content of the system nears 2%.

(2) Such additions of hydrogen or steam also widen the temperature range of carbon deposition in the system, especially as the degree of ore reduction progressively exceeds 50%. Some of the carbon so liberated at 650° and higher temperatures may combine with the freshly reduced iron to form the carbide Fe_3C.

(3) At all temperatures between 650° and 850° small additions

of hydrogen to a $CaCl_2$-dried ore-gas system increase the velocity of ore reduction, especially during its later stages.

(4) The slight influence of steam upon the velocity of ore reduction between 650° and 850° may be positive or negative according to the temperature and CO_2 content of the system.

(5) Small additions of either hydrogen or steam do not eliminate the trough of depression in the velocity of ore reduction at 750° previously observed with a $CaCl_2$-dried ore-gas system; the depth of the trough decreases, however, as the CO_2 content of the gas phase rises.

In conclusion it should be stated that the experimental work embodied in this paper has been carried out in the laboratories of the Bone Research Association, Ltd., at the Imperial College, South Kensington, and has been financed by the British Iron and Steel Federation.

DISCUSSION.

Mr. ALFRED HUTCHINSON, Past-President (Saltburn-by-the-Sea), said he esteemed it a great privilege to have the opportunity of opening the discussion on a question of such importance. As Professor Bone had said, the paper represented the fifth part of the authors' contribution, and was a continuation of most important investigations which had been carried out at the Imperial Institute for some years. It was well known that, although some millions of tons of pig iron had been made in blast-furnaces, as they were made in a vessel into which it was impossible to see, the ignorance as to what went on in a blast-furnace was very profound, and very little work had been done on it since the great book which Sir Lowthian Bell had written nearly seventy years ago, in 1872. Personally, he was very glad that when the research came to be put in hand it was undertaken by a man born in the same district as that in which Sir Lowthian Bell had conducted his experiments, and he would like to congratulate Professor Bone on the energy and determination with which he had pursued his very important investigations through a long period of years. Those who had followed the previous papers would be acquainted with the results which had been obtained, first of all in the laboratory and then in a series of field experiments in the Lincolnshire district. Lately Professor Bone had transferred his attention to the North-East Coast district, where in the plant at Skinningrove, on a furnace which was being rebuilt, it had been possible to give him facilities for making the necessary connections when it was being reconstructed, and those results had been published. The present paper was a continuation of the work and followed on the same lines, dealing with the particular problem which was detailed in the paper.

Everyone must admire the perfection of apparatus and experimental execution which had been achieved in the Imperial Institute laboratories; it was well known what wonderful apparatus had been constructed for carrying out the experiments.

He had not very much to say on the actual results, because they were set out in detail on p. 100 of the paper, and they spoke for themselves. They were extremely interesting, and they threw light on some of the important questions which had made one wonder how far the actual conditions under which the gases acted in the blast-furnace corresponded with the calcium-chloride-dried gas which Professor Bone had previously used. A debt of gratitude was owing to Professor Bone and his assistants for the very useful work which they had done.

Dr. E. GREGORY (Rotherham) said that he was sorry that Mr. Clements, who was such an authority on blast-furnace practice, was unable to be present. Mr. Clements was most enthusiastic about

the work which Professor Bone and his colleagues were carrying out, regarding it as being of vital fundamental importance.

From the results recorded in the paper, it appeared that both hydrogen and steam in small amounts exerted somewhat similar effects on both carbon deposition and the velocity of ore reduction. He would venture to suggest that if steam were added its partial thermal dissociation would be expected, *i.e.*, its dissociation into hydrogen and oxygen. On the other hand, if hydrogen was added one would naturally expect the formation of a certain amount of steam. In the blast-furnace, this dissociation of steam would be expected to take place most readily in the hottest zone, *i.e.*, just above the tuyeres, since the reaction was endothermic. Moreover, he would expect also that the dissociation would occur in actual practice to a greater extent than in Professor Bone's experimental system. That was a point to which the authors might care to reply.

He would like to say a little about carbon deposition. This undoubtedly did take place, as the authors had shown, and in his own works it had been established in practice. The carbon impregnation would appear to account for the disintegration of the lumps of ore as they descended the blast-furnace shaft. He would like to point out, however, that in the blast-furnace the ore was in contact with coke, some of which might descend to a very low level. They, and others, had often observed that by looking through the tuyere spectacles; coke got as far down as the tuyeres. The question arose as to what influence the carbon of the coke had on the carbon deposition, the carbon deposition being accounted for, as the authors rightly pointed out, by the reaction $2CO \rightleftharpoons C + CO_2$. If carbon deposition were to be accepted as being responsible for the disintegration of the ore, it would appear that the influence of coke could not be disregarded, and he ventured to suggest, therefore, that experiments conducted at 450° C. might be more in keeping with actual blast-furnace practice if mixtures of ore and coke were used instead of ore alone.

Professor BONE said that that would be one of the next features of the authors' programme. They had to take one step at a time.

Dr. GREGORY, continuing, said he was very pleased to hear that. Next came the question of moisture in blast-furnace gas. The moisture content of the air entering the blast-furnace varied considerably throughout the year, and it was a well-known fact that the furnace drove most effectively during cold dry weather. Recently at Park Gate they had made comparisons between the coke consumptions during March and during December for one furnace, and, taking corresponding weeks in those two months, they found a considerably smaller coke consumption per ton of iron during March than during December. It would perhaps be remembered that March had been phenomenally cold and dry. The average

moisture content of the burden was about 2% less, and that also might have its effect.

That raised another point. Moisture, as such, one would expect to be driven off at the top of the furnace, but there was the possibility that combined water might be retained at considerably lower levels, and he would ask the authors whether they considered that the combined water had any real effect on either the carbon deposition or the ore reduction velocity.

He would like to refer to the minimum in the ore-reduction velocity curve. The trough of depression appeared to be round about 750° C., and to his mind that temperature had some significance. It seemed to him that it could be associated with the eutectoid temperature of the iron-carbon system, and, if that were so, one had an explanation of why that depression trough or minimum velocity of ore reduction occurred, because it seemed to him that what might possibly occur was this : The iron ore was reduced, and carbon in contact with it formed carbide of iron; the rest of the iron, at a temperature somewhat lower than 750° C., changed simultaneously from the α to the γ condition and dissolved the carbide of iron which had been formed, to yield the solid solution described as austenite. The real magnitude of the energy change from α- to γ-iron, with the simultaneous solution of the carbide to yield austenite was not, he was afraid, always appreciated, and the reaction, using up energy in the form of heat, must have its influence on the velocity of ore reduction.

At temperatures below that of the eutectoid transformation point, say, at 650° C., the iron would exist in the α state after the reduction. No heat was therefore used up, as at the eutectoid temperature, in its conversion to the γ form, and since also the degree of solubility of carbide of iron in α-iron was small below the eutectoid temperature, it followed that the velocity of ore reduction would be greater at temperatures below than at temperatures just above that corresponding with the pearlite–austenite change.

Above 750° C. the input of heat energy progressively increased as the temperature rose, so that the influence of the α–γ change and the solution of the carbide of iron to yield austenite became less marked. In consequence, the velocity of ore reduction would be expected to increase progressively.

Here, then, was an explanation which, he submitted, fitted in with the experimental results obtained by the authors, and he would very much appreciate their views on the matter.

Mr. E. C. EVANS (London) associated himself with what Mr. Hutchinson had said in welcoming Professor Bone. The paper could not be discussed; it was necessary to accept work of this character under the direction of Professor Bone and his colleagues *ex cathedra*. There was an aspect of it, however, which he might

perhaps touch upon, and that was the possible application of the results obtained to practical blast-furnace operation. It was extremely interesting that the presence of moisture and the presence of hydrogen in comparatively small quantities accelerated the reduction velocity. The effect of moisture on blast-furnace operation was well known and had been referred to by Dr. Gregory; in that connection, some few years ago, in a statistical examination of blast-furnace practice, particularly in plants where dry blast equipment had been installed, it had been shown that the effect of moisture was rather peculiar. If one plotted the moisture content in the atmosphere against the carbon consumption in the hearth per unit of iron, it was found that, as the moisture decreased, there was a sudden drop in the carbon consumption in the hearth down to a certain minimum. If the moisture content was decreased below that the carbon consumption rose.

Obviously two conflicting sets of phenomena were operative. The effect of the reduction of moisture on the operation at the outset might be regarded as thermal, but below a certain point that was counterbalanced, possibly, by chemical phenomena, and below that point decreasing moisture resulted in a decrease in the efficiency of the furnace and an increase in the carbon consumption in the hearth.

Possibly, when the moisture had been decreased below the optimum point, any improvement due to thermal considerations would be more than counterbalanced by the decrease in reaction velocity between the gases and solids in the shaft resulting from decreased moisture, in accordance with results submitted by the authors. They could do no more at that stage than put the point to Professor Bone and his colleagues.

AUTHORS' REPLY.

Dr. H. L. SAUNDERS, in reply, said that the remarks made by Dr. Gregory and Mr. Evans were very interesting. Dr. Gregory had referred to the dissociation of steam at high temperatures. That would certainly lead to the possibility of more than 2% of hydrogen existing in the blast-furnace gas, but from the data which the authors had obtained so far, especially with regard to the carbon-deposition reaction, they had shown that a limit was being approached with additions in the neighbourhood of 2%, and any effect that a further quantity of hydrogen was likely to have would be relatively small. He thought it could be taken, therefore, that the major effect was as shown in the paper.

Regarding the possible influence of coke at 450° C., he would expect this to be small in comparison with other factors; the carbon, being deposited throughout the interstices of the ore, disintegrated it with a considerable increase in volume. Chemical examination

of any particle of that ore showed that it contained iron or ferrous-oxide nuclei, and it was that increase in the iron or ferrous-oxide surface which in all probability accounted for the apparently unlimited amount of carbon which could be deposited.

On the question of dry blast being more efficient, that had been stated to be so on many occasions over a number of years, and there was one suggestion which he would like to make; when using a hydrogen-containing or wet gas, might it not be possible that too much carbon was deposited for the requirements of the furnace.

What had been said about combined water persisting at higher temperatures was certainly true, because in the scheme which the authors adopted in their experiments for drying out the gases they showed that quite considerable quantities of moisture could be retained by a partially reduced ore surface even at 750° C., and it was only possible to eliminate such from the ore by circulating over it calcium-chloride-dried nitrogen free from the oxides of carbon.

The question raised by Mr. Evans was rather more difficult to answer directly, and he would hesitate to reply to it without considering it much more fully. It was not just a simple case at all. Mr. Evans suggested two conflicting reactions, but there were more, probably four, and until investigations had been extended up to hearth temperatures he would reserve judgment.

Dr. Gregory's remarks on a possible explanation for the low reaction velocity at 750° C. were very interesting indeed, and it was very gratifying that metallurgists agreed with the authors on that point.

Professor BONE, who also replied, said that in the original plan of the research the authors began by examining the reactions in the most simple form that they could choose, *i.e.*, between a synthetic blast-furnace gas and a pure hematite. The idea was, after establishing the fundamental aspects of the reaction for such a simple case, which they had already done, to add other factors one at a time. In the present instance they had added steam and hydrogen, and they were now proceeding to add calcium carbonate as limestone. They had in contemplation as part of their programme the addition of carbon, and they quite appreciated the importance of what Dr. Gregory said. They could not, of course, rush matters, and he thought that it was better, when investigating the fundamentals of reactions, to add " side " factors one at a time and so be quite sure that one's findings would establish their true influence. If one started in too complicated a way—and the complications inside a blast-furnace were really enormous—one would lose one's way, and never be able to assign a particular effect to a particular cause.

With regard to the carbon, of course the carbon from coke was

very different from that deposited from CO. The carbon deposited from the gases was very much more active than any carbon which was added, because deposited carbon was the most active form which could be obtained. The authors quite agreed with Dr. Gregory that carbide of iron was in part, and perhaps to a great extent, responsible for the trough. They regarded that trough as due to a change in the mechanism of the reaction, and had said so in the paper. He was very glad that Dr. Gregory had arrived, by different reasoning, at that conclusion, because the authors had not yet proved it; but it was their strong suspicion, and no doubt as the work advanced they would come to that point.

People talked about the dissociation of steam in the blast-furnace, and there was no doubt that in the region of the hearth, where there were very high temperatures, dissociation of steam did take place. Dissociation of steam at high temperatures used to be put down as $H_2O \rightleftharpoons H_2 + O$, but a great deal of work during the last ten years had shown that H_2O dissociated also into $HO + H$, a free hydroxyl and a free hydrogen atom which was more reactive than H_2. The effect of that dissociation was much more likely to be potent than the other. It might be asked whether OH would exist freely in any quantity when it was in contact with carbon and carbonic oxide and so on. There was spectrographic evidence, as he had found in connection with other research work, that OH would be formed at an extremely high temperature in quite considerable amounts, and even in the presence of a large excess of oxygen or a very large excess of reducing gases such as CO or even hydrocarbons. It was a very persistent and potent feature of hydrocarbon and hydrogen flames, and the probability must not be overlooked that at the high temperatures of the hearth one had to deal with free OH, and a free hydrogen atom, which would be very active. It would probably not exist at the lower temperatures in the stack, but nowadays one must not assume anything. When the authors came to examine some of the reactions in question he expected they would find that OH and H were playing some part in the reducing reactions there, and that was something for which they must be on the look out. Great advances had been made in our ideas of the entities which were concerned in very high-temperature reactions in flames. Our knowledge and outlook on such points had completely changed in the last decade or so, since the spectroscopic investigation of flames had been taken up systematically. That, however, was a matter which could be taken up later.

He would like to thank Mr. Hutchinson for his kind remarks.

SOLIDIFICATION IN OPEN-TOPPED AND CLOSED-TOPPED INGOT MOULDS.[1]

By BERNHARD MATUSCHKA (Ternitz, Lower Austria).

(Figs. 9 to 20 = Plates I. to III.)

Synopsis.

The author first discusses certain factors which exert a profound influence on the piping of steel ingots; the influence of casting temperature and of the ratio of the ingot weight to that of the ingot mould are considered at length. Graphical data are presented with respect to the momentary volumes of solidified steel to momentary heat loss and to the course of solidification in ingots of different diameters. It is demonstrated that freezing and piping proceed rapidly both at the commencement and shortly before the completion of the solidification process. The relative importance of the decrease in volume of the steel on cooling down to the freezing point, of the shrinkage on transition from the liquid to the solid state and of the contraction on cooling down to room temperature are also discussed in connection with the degree of piping.

In dealing with the mechanism of piping, it is stated that piping originates from and presupposes a contractile process in the liquid or solid part of the ingot. The effect of thermal contraction phenomena in the ingot upon the formation of the pipe are considered with particular reference to the influence of the shrinkage of the frozen ingot skin upon the course of solidification of the still molten interior of the ingot. Explanations are advanced, based on the interference introduced into the normal thermal contraction of the molten steel by the mechanical and physical influence of the solidified ingot skin and by the ferrostatic pressure of the molten metal, for certain structural peculiarities and for the occurrence, under given conditions, of gas evolution and the formation of blow-holes. By consideration of the motion of the molten metal contained within the ingot skin during the progress of solidification, simple explanations are educed for the well defined and sudden transition from a columnar zone to a zone of small equiaxed crystals and for the inclined position of the segregates at the ingot rim—the so-called L-segregates. The effect of ingot shape upon the characteristics of segregation and of blow-hole formation is examined.

The results are discussed of an investigation carried out on ingots of a basic open-hearth steel employed for the manufacture of railway wheels, and comprising the examination of the pipe formation in ingots solidified under various conditions both as to open-topped and closed-topped ingot mould practice. It is shown that relatively slight variations of pressure exert an appreciable influence on the capacity of a steel ingot for retaining gases in solution. Solidification in open-topped moulds and the maintenance of an open pipe by means of a heat-generating medium ("Lunkerit") assist in the

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production of a dense steel free from flaws. It is also demonstrated that slight decreases in pressure arising as a result of the solidification process in the body of the ingot may lead to gas evolution of a type producing abnormal piping and detracting from the quality of the steel.

Introduction.

The most important factors controlling the cooling and freezing processes are casting temperature, rate of pouring, temperature of the ingot mould, volumes of ingot and mould, composition and tendency to undercooling of the steel, contraction and heat conductivity. Most of these factors have been the subject matter of exhaustive research. The following principles may be considered regarding circumstances favouring piping and segregation.

By raising the pouring temperature, the contraction and, therefore, the piping of any given steel will be increased. The total decrease in volume of the steel on cooling and freezing is made up of the contraction which takes place until the freezing point is reached, the shrinkage on transition from the liquid to the solid state and the contraction on cooling down to room temperature. The shrinkage on freezing may be taken as about 3·8–4%. For every 100° C. of superheating the density of the metal decreases by approximately 0·4%. The contraction on cooling from the melting point to room temperature is, according to investigations by Desch, about 8%. The 4% shrinkage on freezing and the contraction of the liquid metal down to the freezing point may be considered of principal importance in connection with the formation of piping.

The pouring temperature influences the degree of superheating. Superheating by 100° C. increases the piping by about a tenth. From the completion of pouring to complete solidification a shrinkage of about 4·4% may be expected. This figure may be verified by estimating the capacity of the pipe in ingots solidified in open-topped moulds. It was found, for example, in a 360-kg. ingot that the volume of the pipe was 1·4 cu. dm., corresponding to $1{\cdot}4 \times 7 = 9{\cdot}8$ kg. of steel or about 2·7% of the ingot weight. A number of explanations may be given for the fact that the entire contraction of the liquid steel does not reveal itself as piping. Owing to the chilling effect of the mould a cylindrical skin rapidly freezes on the ingot; this skin tends to contract in opposition to the internal ferrostatic pressure. A linear decrease of the circumference by about 1·0% corresponds to a volume decrease of 1·99 or 2%. With a preheated cover solidification begins somewhat later and the surface of the steel remains at first flat as the level drops. A fall of 1 cm. corresponds in the case previously cited to about 1%. Apart from these causes a difference in the measured volume of the pipe in the ingot head can be explained by secondary piping and by blow-holes in the interior of the ingot. With all other conditions equal the cavity in the head of an open-topped ingot is a good

means of determining the correct degree of piping and the quality of the ingot. So far as it goes, this method is of general application where the determination is made by estimating with the unaided eye. More accurate conclusions are arrived at by determining the capacity of the pipe by pouring in a liquid after the ingot has cooled down. Minute differences may be detected in this way. Decreased capacity of the pipe in the ingot head signifies cavities in the interior of the ingot.

As further factors may be adduced the dimensions of the ingot and mould. It is usual to regard the ratio of the weight of the ingot to that of the mould as a criterion.

In Fig. 1 are given the momentary volumes of solidified steel per sq. cm. of ingot surface for ingots of three different diameters, namely 200 mm., 250 mm. and 340 mm. In the first few minutes the

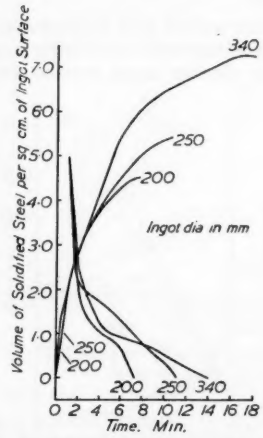

Volume of Solidified Steel per sq cm. of Ingot Surface
Time. Min.
Ingot dia in mm
340
250
200
0 2 4 6 8 10 12 14 16 18
0 1·0 2·0 3·0 4·0 5·0 6·0 7·0

FIG. 1.—Momentary Volume of Solidified Steel per sq. cm. of Ingot Surface for 700-kg. ingot 340 to 290 mm. in dia., 350-kg. ingot 250 to 215 mm. in dia., and 200-kg. ingot 200 to 180 mm. in dia.

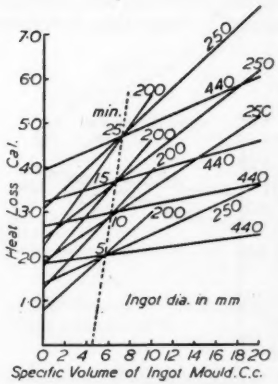


FIG. 2.—Momentary Heat Loss in Relation to Volume of Mould Material Corresponding to 1 sq. cm. of Ingot Surface for Ingots 200, 250 and 440 mm. in dia.

curves cut each other extensively. For the first part of the freezing process, therefore, the ingot surface is a deciding factor. It may also be seen from this diagram that the amount of steel frozen at any given time is greatest initially and then falls rapidly. The contraction (piping) resulting from freezing naturally obeys the same laws.

Fig. 2 shows the momentary heat loss deduced from measure-

ments, for ingots of 200 mm., 250 mm. and 440 mm. dia., in relation to the volume of mould material corresponding to 1 sq. cm., of ingot surface. The influence of the volume of mould material (thickness of wall) increases with the progress of time and is more pronounced with the ingots of smaller diameter. The effect on the volume of the solidified ingot is, however, not so outstanding, as may be seen from Fig. 3.

For ingots of a given volume the surface of the ingot is related to the diameter thus :

$$O = \frac{V}{D}$$

that is, for equal volumes the surface will increase for smaller diameters. The specific volume of the ingot mould,

$$V = d\left(1 + \frac{d}{D}\right),$$

where d is the thickness of the wall of the mould and D the interior diameter, increases with increasing wall section and decreasing ingot diameter. From this, it follows that a slender ingot freezes more

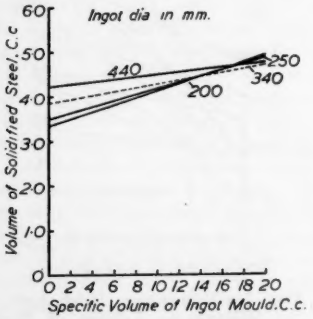

Ingot dia in mm.
440
250
340
200
Volume of Solidified Steel. C.c
Specific Volume of Ingot Mould.C.c.
0 2 4 6 8 10 12 14 16 18 20
0 1·0 2·0 3·0 4·0 5·0 6·0

FIG. 3.—Influence of Wall Thickness of Ingot Mould on Momentary Volume of Solidified Steel (after 5 min.).

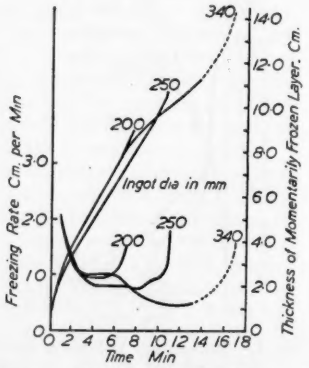


FIG. 4.—Momentary Thickness of Solidified Ingot Shell and Rate of Solidification.

quickly than one of heavier section. According to Field, $\delta = K\sqrt{T}$, or, for completed solidification, $D/2 = K\sqrt{T}$, that is, the freezing time, $T = (D^2/4) \cdot (1/K) = C \cdot D^2$, is proportional to the square of the ingot diameter. The progress of solidification in the three ingots—the increase in the thickness of the skin and the freezing rate in a horizontal direction—is shown in Fig. 4. Solidification proceeds very rapidly at first, then becomes slower and quite near the end of the freezing process rapidly increases again.

Fig. 5 illustrates the results of measurements of the progressive freezing of a 200 mm., 250 mm., 350 mm., and a 20-ton ingot of 1400 mm. dia., in a vertical plane. Solidification in this direction also proceeds slowly to the point where the solidified lateral zones are drawing nearer together and the centre of the ingot almost simultaneously becomes solid over its entire length. This moment is significant in regard to the formation of the pipe. A marked decrease in volume takes place suddenly, and sufficient hot liquid material should be present in order to flow into the cavity caused by the contraction. Later, solidification occurs in zones higher up and near to the ingot head into which hotter steel has previously run; the solidification rate is diminished here. This rests on the assumption that the material in the head of the ingot has been maintained hot and fluid so that this can take place. In the case of the 20-ton

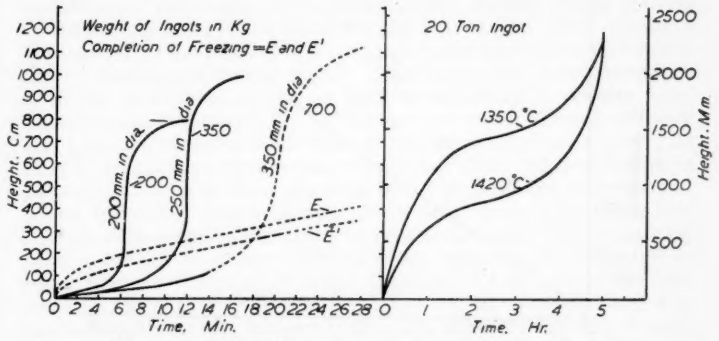


FIG. 5.—Progress of Solidification in a Vertical Direction. Momentary thickness of solidified layer at lower end of ingot.

ingot solidification is also initially rapid, then somewhat slower and finally is again strongly accelerated.

The researches have thus demonstrated that freezing (piping) proceeds rapidly both at the beginning and shortly before the completion of the solidification of the ingot. In Fig. 5 is recorded, in addition to complete solidification, the critical moment of sudden freezing of the interior of the ingot as a function of the ingot diameter.

MECHANISM OF PIPING.

Consideration of the piping processes starts from the fact that every occurrence of piping in liquid steel originates from and presupposes a contractile process in the liquid or solid part of the ingot. Solidification, or the transition from the liquid to the solid state accompanied by about 4% contraction, accounts for the major part

of the shrinkage. Moreover, this contraction occurs suddenly and is localised. Shrinkage through the cooling of the fluid parts of the ingot results from heat transfer and temperature gradients throughout the entire section of the still fluid interior of the ingot and with respect to time takes place gradually from the initial temperature of the molten metal until the freezing point is reached. The shrinkage of the fluid portion of the ingot contributes a much smaller share to the process—only about one-tenth of the contraction due to freezing—and is only a supplementary (secondary) effect; in considering fundamental principles it may probably be neglected. Contraction due to cooling of the solid part of the ingot is very difficult to estimate. An indication is furnished by the curve in Fig. 6, in which is plotted

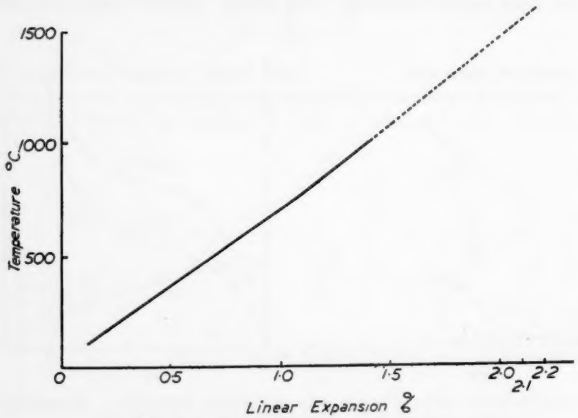


FIG. 6.—Linear Expansion of Iron.

the percentage linear expansion of iron in the form of small rods, extrapolated to the melting point. As may be seen, the linear expansion to the point of fusion amounts to 2·1%, equal to a shrinkage of 2·05%. This corresponds to a volume decrease of 6%.

With moulds of usual wall thickness it may, according to the author's own investigations, be taken that the external temperature of the ingot at the completion of solidification is about 600° C.; this gives a mean temperature for the solidified skin of the ingot of $\frac{1}{2}(1500 + 600) = 1050°$ C. The linear expansion (contraction) between 1500° C. and 1050° C., is, according to Fig. 6, 2·2 — 1·5 = 0·7%. The volume decrease, then, amounts to about 2%. The decrease in the volume of the pipe due to contraction of the ingot skin may thus be estimated at 2%. If this figure is inserted in the original calculation the results for a 360-kg. ingot would be as

follows : Shrinkage to point of solidification 4·4%, equal on an ingot of this weight to 15·4 kg. ; but the volume of the pipe is decreased by 2%, which is equivalent to 7 kg., therefore the volume of the pipe equals 2·4%, which is equivalent to 8·4 kg. of steel. The ratio of 8·4 to 7 gives 1·2 cu. dm. Actually, the measured volume of the pipe was 1·4 cu. dm. Considering the crude assumptions made, this agreement is very good. As a first approximation for the considerations which follow, a mean ratio between the volume of the contraction on freezing and that of the pipe of 4·5 : 2·4 will be assumed, that is, the volume of the pipe is 54% of the theoretical contraction of the ingot.

In reality, this ratio will apparently not remain constant during the solidification process. At the commencement of freezing it is known that separation of the ingot from the mould soon begins. The shrinkage of the solidified ingot skin will then keep pace with the decrease in volume of the freezing steel so that piping (falling of the surface level of the steel) will not take place. Only when the contraction of the ingot skin is completed and the latter has become strong does piping proper begin. This conception is in accordance with the actual behaviour, as may be determined visually from observations on the ingot head if this is not covered. Simultaneously the heat transference and rate of solidification drop rapidly, as shown in Fig. 4, and approach a constant value. This variation in behaviour, which is often preceded by no preliminary changes, and which frequently produces with great suddenness a complete and sharply differentiated alteration in crystal structure, has repeatedly been a subject of interest and has been variously investigated in order that an explanation might be found for it. In a previous research the author has already pointed out this phenomenon, and has adduced that the temperature in the molten steel may remain for some time at about the same level and adjust itself to a thermal solidification equilibrium. The author has demonstrated that some irregularity occurs between the fourth and eighth minute by means of the heat transfer figures (Fig. 3, temperature-time curve). According to the present investigations this process may be described as follows : As long as the externally frozen ingot skin keeps pace by shrinking with the void formed by the process of solidification and contraction, a continued growth of crystals towards the centre of the ingot takes place—columnar crystallisation. As soon as the skin of the ingot is sufficiently strong so that further shrinkage ceases and heat transfer through the mould becomes less, a region of decreased pressure forms at the interface between the liquid and solid, which arrests the growth of the ingot skin so that the liquid metal in the interior of the ingot commences to move towards the frozen surface and piping begins. As a result of this decrease in pressure, gas is evolved from the molten interior of ingots of rimming steel and occurs as blow-holes in the solidified skin of the ingot. With killed steel no gas is evolved as a rule, the low pressure being

equalised by material flowing into the region in question, thus initiating piping. Whilst in metallurgical processes in the melting furnace a constant pressure of about 1 atm. may be assumed, the pressure in the fluid interior of an ingot varies according to the height of the ferrostatic column which rests upon the steel. Fig. 7 shows the pressure conditions at different distances from the upper surface of the metal at the ingot head. By assuming the weight of liquid steel to be 7 kg. per cu. dm., the pressure at the base of a mould 1·4 metres high amounts to 2 atm., that is, double the pressure at the ingot head.

It follows from these circumstances that the ingot skin has to overcome an appreciably higher pressure as a result of shrinkage in the lower part of the ingot. From this it follows that the drawing

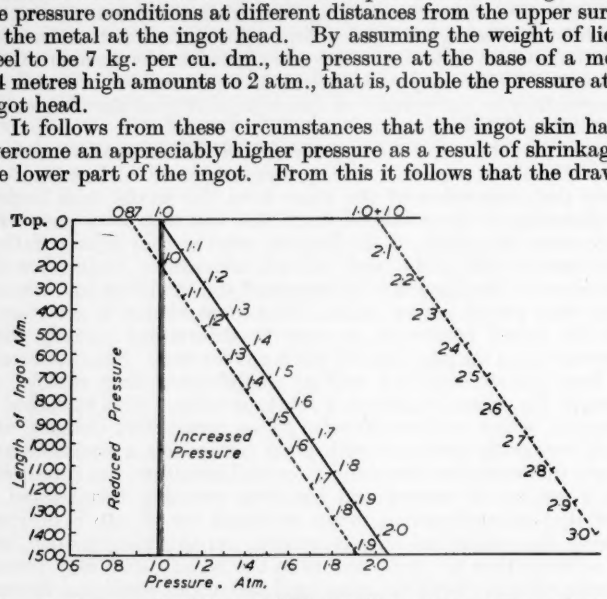


FIG. 7.—Pressure Conditions at Different Distances from Upper Surface of Metal in Ingot Mould.

away of the metal from the walls of the mould takes place at the top of the ingot before it occurs at the bottom. The more pronounced nature of the columnar zones in the lower part of the ingot may originate from this cause. In so far as piping is concerned it follows from this circumstance that the pipe begins locally in the lower part of the ingot and is aided by the freezing of the base of the ingot itself. The column of molten steel keeps pace with the decrease in volume of the skin in the lower part of the ingot by sinking in the centre, which introduces the piping process. In due course, after solidification, a decrease in volume of the complete side wall of the ingot occurs and the piping process increases in intensity.

For the considerations which follow, the rapid drop in heat transfer—cooling velocity—is significant. As a result of this the volume of the cavity due to piping which has to be filled up decreases sharply. The fluid column in the centre of the ingot initially set

flowing in a downward direction is prevented from continuing in this direction on reaching the base of the ingot, and near the side walls is given an upward motion. If this conception is correct, then the rapid solidification of the ingot skin which takes place after pouring but which soon slows down would cause a convective movement in the liquid interior of the ingot, which consists of a sinking of the centre and a rising of the exterior along the length of the solidifying surface. This type of movement may be simulated to some extent by the process of pouring water into a water-bottle, although the processes previously described take place much more slowly. The sharp drop in the solidification rate to an approximately constant value is thus of special significance.

This assumption permits a ready explanation of two known solidification phenomena : The sharp and immediate transition from the columnar zone into one of small equiaxed crystals owing to the interference in the temperature drop in the vicinity of the solidifying surface; the inclined position of the rim segregates—L-segregates—in large ingots, and their striated structure. The inclined position is explained as resulting from the horizontal cooling rate of the ingot skin and the perpendicular ascending movement of the fluid zone at the rim. The striated structure of the L-segregates is explained by the movement of the apparently more viscous mother-liquid which has been pushed towards the centre of the ingot by the crystals (skein formation).

On the other hand, the solidification equilibrium referred to earlier finds a simple explanation in the movement—mixing—of the liquid phase and the equalisation of temperatures along the freezing surface, and the uniform progress of freezing and heat transfer.

If it is considered that in the piping accompanying solidification the contraction cavity in the head of the ingot must be refilled, the conception of rate of descent is arrived at, that is, of the quantity of steel which descends from across the ingot head per unit of time into the body of the ingot. For a given surface of solidification (surface of ingot) the rate of descent is equal to the volume of the ingot frozen at any given moment multiplied by the surface of the ingot multiplied by a constant and divided by the cross-section of the ingot head :

$$Va = \frac{Vt \,.\, O}{Q} \,.\, C$$

where $C = 0{\cdot}025$ (2·5%).

The rate of descent is now a measure of the descending motion introduced into the interior of the ingot.

If it is assumed that too rapid an ascent along the length of the ingot shell is not favourable to the equalisation of the concentration of the segregates with the surrounding material, the necessary conditions which should obtain in order that Va may be low may be deduced from the above equation. This is the case if Vt, the volume

of the ingot material solid at any given moment, is small and the transverse section of the head is large. With all other conditions equal the volume of the ingot material solid at any given moment is small for a smaller surface of solidification (ingot surface), that is, with short ingots of large diameter. In this latter case naturally the section of the head will also be greater.

Thus it follows that short thick ingot shapes induce more favourable conditions for segregation. This actually agrees with practical experience.

To return to a consideration of the second critical region of solidification : The period shortly before the completion of freezing.

It will have already been gathered from Fig. 4 that the momentary

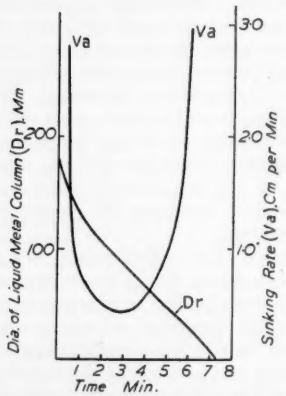


FIG. 8.—Momentary Decrease in Diameter of the Liquid Metal Column in a 200-kg. Ingot, 200 to 180 mm. in dia.

freezing rate is initially very high, then exhibits a decrease and towards the end again increases. If the respective values of the volumes of the ingot solidified per minute are converted into the values for the volume of piping, and if the rate of descent is determined in the still fluid transverse section (qr) of the ingot, then

$$Va = \frac{Vt \cdot O}{Qr} \cdot C$$

and the parabolic curve for Va shown in Fig. 8 is obtained. This curve shows clearly that the rate of descent, like the rate of solidification, is very high at the beginning and end of the freezing process.

Shortly before the end of the freezing process the piping motion in the still fluid axis of the ingot rapidly attains a maximum value, if at the end of freezing strongly cooled viscous steel is able to attain this rate in spite of its high viscosity under

the influence of atmospheric pressure and ferrostatic pressure. If this is not so, then a region of low pressure must form. If this is below the dissociation pressure of carbon monoxide, hydrogen and nitrogen for the temperature obtaining, then evolution of gas occurs. The reaction $FeO + C \rightleftharpoons CO + Fe$ will proceed strictly according to the law of mass action, $K = \frac{p_{CO}}{FeO.C}$, on lowering the temperature and on enriching the residual fluid metal in FeO, towards the formation of carbon monoxide, and to an increased degree when the pressure p_{CO} increases. In actual fact it is possible to find in high-carbon-steel ingots containing 1·0% of carbon and upwards blow-holes in the enriched **V**-segregates in the vicinity of the ingot axis. In such cases the **V**-segregates with their accompanying blow-holes may penetrate to the lower third of the ingot, and there, since the pressure is at a maximum, vanish. Nevertheless the part of the ingot beneath the head may be free from them, since here the gas bubbles can rise owing to the low pressure obtaining and to the higher fluidity of the steel. The fact that the gas bubbles attach themselves to the lower part of the segregates is due undoubtedly to the rapid descending motion of the steel.

The values recorded in Fig. 8 for the rates of descent are determined on the assumption that the entire cross-section of the residual melt takes part in the movement. As has been indicated, there are reasons to believe that only the innermost zone at the axis of the ingot descends under atmospheric pressure, whilst along the inner wall of the solid ingot skin turbulence and counteracting ascending movements take place. The rate of descent in this limited axial zone may therefore be *de facto* higher than that determined for the whole section. On the other hand, for the calculation of *Va* on the basis of the total ingot surface, *O* applies strictly speaking only to upper parts of the ingot and falls in lower zones, down to the base of the ingot, and, corresponding to the lesser surface of the accompanying cylindrical form of the ingot, to a minimum value. *O* is the base area of the ingot (when not, as indicated, set in a circulating motion by the forces acting in the fluid column—downwards at the centre of the ingot and upwards at the outer areas).

Again, if it is assumed that a high rate of sinking at the completion of solidification is unfavourable to segregation in the centre of the ingot, the above considerations permit the necessary conditions to be deduced which must be maintained in order to avoid the formation of **V**-segregates. It follows from the relationship $Va = \frac{Vt \,.\, O \,.\, 0{\cdot}025}{qr}$, where qr has a small given value, that only by decreasing *O*, and, if necessary *Vt*, can a low rate of descent be obtained. For **V**-segregation also the short thickset ingot with a small surface *O* is advantageous, presupposing that the steel in the ingot head is maintained sufficiently hot to correspond to the long freezing period of thick ingots. A second measure, however,

namely, pronounced conical formation, also decreases the solidification surface for a given diameter of the residual melt, prevents the occurrence of circulation and converts the solidification process at the ingot axis, which takes place over the whole length simultaneously, into a solidification process that proceeds momentarily and successively from the base to the head of the ingot. Practice has confirmed these considerations.

The volume of ingot material frozen at any given moment, Vt, can, towards the end of the freezing process, undergo a diminution through thermal insulation of the mould.

Solidification in Open and Closed Ingot Moulds.

Steel ingots cast in moulds are either allowed to cool freely, or free cooling from the upper surface of the steel is prevented by covering it with badly conducting or heat-giving compounds; in the last case prevention of premature solidification of the ingot is aimed at. These measures result from the general striving to obtain high-quality steel ingots. As further aids to this end, bricking up of the ingot head with thermally insulating materials, preheating of the ingot head, feeding of the ingot head with hot steel, special forms of cover, &c., are used. By all these methods the effect striven for is more or less perfectly attained, according to the type of steel, the skill of the steelworker and the demands made of the finished product. In one respect the methods employed to avoid piping depart fundamentally from one another, that is, in whether the pipe remains open towards the top until the end of solidification or is prematurely closed by means of a frozen steel cover. These procedures are referred to shortly as open- and closed-topped mould solidification. The open-topped method finds nowadays frequent application on the Continent; the closed-topped method, the older procedure, is widely met with in England and in Scandinavia.

The investigations which follow are concerned with the different conditions which obtain in open- and closed-top mould practice and with the experiences obtained with both.

Various observations made during the manufacture of wheel discs for railway wheels gave occasion for a closer investigation of the conditions of freezing in open- and closed-top moulds.

A basic open-hearth steel was used containing about 0·2% of carbon, 0·7% of manganese and 0·25% of silicon. Fig. 9 illustrates an ingot usually employed for this purpose cast without a feeder head and exhibiting a normal pipe. Fig. 10 shows a similar ingot in which the pipe has divided itself in part into separate shrinkage cavities. Fig. 12 shows another such ingot from the head of which a disc 30 mm. thick has been cut. The original conclusion, namely, that in this case the recognised phenomena associated with gassy melts had been met with, proved invalid. Ingots of the same melt could exhibit either type of piping. Ingots which were cast with an open

FIG. 9.—Railway Wheel Ingot, basic O.H. steel, 0·2% carbon. Cast without feeder head.

FIG. 10.—Basic O.H. Steel Ingot. Partial division of pipe into separate shrinkage cavities.

FIG. 11.—Ingot with Contracted Neck.

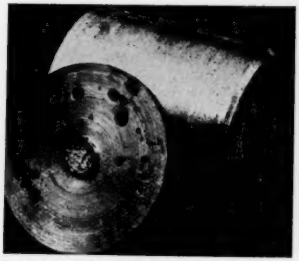


FIG. 12.—Basic O.H. Steel Ingot. Shrinkage cavities.

[*Matuschka.*

[*To face p.* 120 P.

FIG. 13.—Ingot with Contracted Neck.

FIG. 14.—Pronounced Division of Pipe in Ingot.

FIG. 15.—Wheel Ingot, final form.

FIG. 16.—Wheel Ingot, final form.

[*Matuschka.*

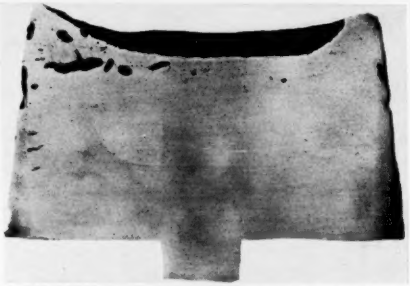


FIG. 17.—Head. Pipe kept open with "Lunkerit."

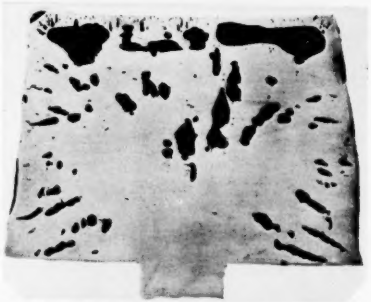


FIG. 18.—Head. Cast with crop end and allowed to cool freely.

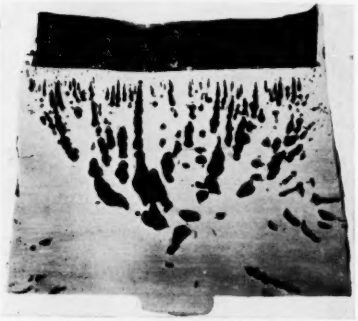


FIG. 19.—Cast in Closed-Topped Ingot Mould.

FIG. 20.—Solidified under 2–3 Atm. Pressure.

FIGS. 17 to 20.—Ingots of 0·12% Carbon Basic O.H. Steel.

[*Matsushita.*

UNIV. OF MICH.

pipe piped deeply without difficulty. Since these ingots were cooled with water after pouring, in order to obtain a flat top, thus giving opportunity for moisture to enter the steel, the ingot-mould shape was altered. Figs. 11 and 13 illustrate ingots of the new shape with contracted necks. It will be seen that the same pipe formation is also possible in this case. A further form of ingot with a particularly strongly dispersed pipe is illustrated in Fig. 14. The final wheel-disc ingots are shown in Figs. 15 and 16. In these types also, both varieties of piping occurred. Attempts at the employment of a small feeder head and with the use of an open pipe—obtained by means of "Lunkerit" heating powder—led to the required result. Dispersed pipes did not make their appearance with this method of working.

It may be of interest to note that divided pipes similar to that illustrated in Fig. 14 appear in steels containing up to 1·6% of silicon cast in closed-topped ingot moulds. It was to be concluded from a full consideration of the freezing process as taking place in an entirely closed space and from the arrangement of the shrinkage cavities that the occurrence of the divided pipe was due to gas evolution in the ingot owing to low pressure.

When an ingot of liquid steel cools and solidifies from every surface and the interior of the ingot is sealed from the atmosphere by a sufficiently thick skin, then, on further solidification of the liquid residue of the ingot, the volume of the steel will decrease owing to the contraction of this part of the melt on changing from the liquid to the solid state. Since air cannot enter in the place of steel, the entrapped gas will be rarified and decreased pressure result. Gases which remain dissolved in steel under a pressure of 1 atm., reactions between carbon and dissolved iron oxide, $FeO + C = CO + Fe$ which up to that time had reached equilibrium, will, because of the decreased pressure, proceed further with the formation of carbon monoxide. Hydrogen and carbon monoxide are evolved, and attach themselves to the solidified ingot skin. The pressure of the gases exceeds the existing low pressure in the interior of the ingot. The same occurs in normal ingots when, as a result of the concentration conditions of hydrogen and ferrous oxide, the gas pressure exceeds 1 atm., that is, the ingots rise. It will be seen that the usual conditions of fabrication are equated to a pressure of 1 atm., but that these conditions are no longer entirely valid for other conditions as to pressure. In an analogous manner to vacuum casting, gases are evolved from steels when they are manufactured by closed-topped ingot mould practice and render the ingots useless, although at 1 atm. deoxidation and degasification have proceeded sufficiently far to yield sound ingots.

These conditions are clearly illustrated in Fig. 7. In open-mould practice atmospheric pressure prevails at the ingot head. At the base of the ingot at a distance of 1300 mm. the pressure is $1 + 1 = 2$ atm.

If the pressure in the interior of the ingot falls to about 0·83 atm.,

then the pressure in the ingot reaches 1 atm. at a depth of 200 mm.; at depths less than this, reduced pressures obtain and gas may be evolved.

In order to verify the effect of pressure, four ingots of a soft basic steel containing 0·12% of carbon, 0·49% of manganese, 0·26% of silicon, 0·014% of phosphorus and 0·019% of sulphur, were cast under various conditions as to pressure.

Fig. 17 illustrates the head of an ingot cast in the usual way, the pipe being kept open with "Lunkerit." Except for a small residue in the topmost part of the ingot head the material is free from blow-holes and the formation of the pipe and the ingot is ideal.

Fig. 18 illustrates the second ingot cast with a crop end, without the use of any heating compound and allowed to cool freely. The head exhibits a partly divided pipe, with normal shrinkage cavities in the upper part so long as contact was still established with the atmosphere; then with the onset of reduction of pressure caused by the exclusion of air the pipe split up into blow-holes with a pressure centre half-way up the feeder head. The blow-holes extend downwards into the ingot.

Fig. 19 illustrates an ingot into which directly after casting a cast-iron plate was pressed from above in order to produce rapid solidification of the surface of the steel and to exclude air at the earliest possible moment. It will be seen that already in the topmost part the pipe has divided up into small blow-holes. The pressure centre in this case lies deeper on the lower projection of the head. The blow-holes likewise penetrate into the ingot.

Finally, Fig. 20 illustrates an ingot which was solidified under a pressure of 2–3 atm., by means of a pressure head screwed on to the ingot mould. The pipe reaches, it is true, to the body of the ingot itself. The ingot head, however, is perfectly dense and free from blow-holes, as also is the body of the ingot.

The results of this series of experiments demonstrate that relatively slight pressure variations exert an appreciable influence on the gas-retaining powers of a steel ingot. Open-mould solidification, by uncovering the head and heating it by means of "Lunkerit," is advantageous for the production of dense ingots free from flaws.

From this research it may also be concluded that slight decreases in pressure arising as a result of the solidification process in the body of the ingot may lead to transitory or permanent gas evolution. This supports the conception of the mechanism of piping as described at the beginning of this paper.

CORRESPONDENCE.

Professor A. PORTEVIN and Mr. P. PIERARD (Paris) wrote that they had much appreciated the author's very interesting paper which dealt with phenomena of both academic and technical importance.

Among the points dealt with in the paper they would deal only with the influence of pressure on the conditions and velocity of the evolution of gas at the moment when the steel was freezing. Certain remarks in connection with the crystallisation of ingots would be reserved for a future occasion.

The effect of pressure on the evolution of gas during freezing was well known and was a general phenomenon occurring in the presence of reaction gas and of dissolved gas. Thus, in the case of aluminium alloys, Professor D. Hanson [1] had shown that pressures of the order of 15 kg. per sq. mm. inhibited the formation of blow-holes in alloys which had absorbed gas and produced well-defined piping. Conversely, the formation of well-marked blow-holes on casting under reduced pressure was utilised in practice to determine the liability of metals and alloys to such blow-hole formation on solidification. With regard to steel this effect was demonstrated by a number of observations, for example :

(1) In ingots of effervescing steel, the discontinuity in the oxygen and carbon contents and in the structure of the metal, on passing through the layer of deep-seated blow-holes, was associated with the sudden crystallisation of the whole mass of liquid metal occupying the interior of the ingot. This mass, previously agitated by the effervescence, assumed a practically uniform temperature, and at a particular moment crystal nuclei were formed throughout its volume. The suddenly increased viscosity hindered the evolution of gas from the surface of solidification—hence the deep-seated blow-holes. Then the ingot head froze rapidly and further solidification took place under pressure. As a result of this, in the interior of an effervescing ingot a species of semi-killed ingot was obtained which solidified with the formation of numerous blow-holes and a small pipe. Example No. 24 of the Committee on the Heterogeneity of Steel Ingots [2] was a typical case in point. It must be noted that if in the course of solidification of such an ingot the skin at the head was pierced, a violent evolution of gas under pressure took place and liquid metal was expelled from the opening.

The relative importance of the pipe and of blow-holes varied as in the case of semi-killed ingots. Example No. 65 [3] of the Ingot Com-

[1] *Journal of the Institute of Metals*, 1935, vol. 56, p. 103.

[2] Second Report on the Heterogeneity of Steel Ingots, *Journal of the Iron and Steel Institute*, 1928, No. I., p. 480.

[3] Sixth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1935, *Special Report No.* 9, p. 23.

mittee, in comparison with example No. 24, showed a reduction in the volume of the pipe with a corresponding increase in deep-seated blow-holes.

(2) In effervescent ingots the influence of ferrostatic pressure was to retard the evolution of gas at the bottom of the ingot. Effervescence commenced then in the upper part of the ingot, since the liquid metal was completely saturated with gas under atmospheric pressure. The condition necessary in order that a bubble of gas should not remain entrapped and so form a blow-hole was that it should increase in size sufficiently rapidly in relation to the progression of solidification so as to be able to free itself and reach the surface. This happened in the upper part of the ingot, whilst at the bottom of ingots of ordinary steel containing 0·3-0·5% of manganese the formation of gas bubbles was sufficiently slow for certain of them to be entrapped by the columnar crystals growing from the walls towards the interior of the ingot. These blow-holes in the ingot skin were particularly noticeable in example No. 24 already referred to.

On the other hand they did not occur in ingot No. 62.[1] In this case the ingot was much oxidised and had a carbon content of 0·05% together with 0·05% of manganese.

(3) Conversely, example No. 68 [2] of the Ingot Committee demonstrated the effect of ferrostatic pressure in completely preventing the evolution of gas when the tendency in this direction was small. This ingot, which had been killed with aluminium, but not quite sufficiently, was quite sound in its lower part, whilst in the head the gas bubbles formed very slowly and were entrapped by columnar crystallisation or were pushed by the crystals before them as these grew in a radial direction. The gas evolved compensated for the shrinkage so effectively that no pipe formed.

(4) The range of semi-killed steels also demonstrated very well the effect of pressure on the formation of blow-holes. Starting with killed steel and decreasing the additions of deoxidisers (that was to say, reducing agents in comparison with the oxygen dissolved in the liquid steel), ingots were at first obtained free from blow-holes in the skin but with the pipe partly replaced by several deep-seated blow-holes. With still smaller additions of deoxidiser blow-holes were observed in the skin of the upper part of the ingot, the lower half being sound (example No. 41 of the Committee). Ingots which had received still smaller additions of deoxidiser exhibited, when cast in closed or closed-topped ingot moulds, blow-holes in the skin, the formation of which occurred before the top was closed and was accompanied by a rising of the metal. When the top was closed the increase in internal pressure counteracted the evolution of gas and no more blow-holes were produced. The balance between

[1] Fifth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1933, *Special Report No.* 4, p. 32.

[2] Sixth Report, *loc. cit.*, p. 31.

piping and the formation of deep-seated blow-holes was finally established according to the degree of carbon segregation and to the amount of iron oxide, and also, it appeared, according to the permeability to gas of the solidified skin.[1]

Dr. Matuschka drew attention to the fact that shrinkage on solidification created a region of low pressure in closed ingots favourable to the evolution of gas. This reaction led to the substitution of disseminated blow-holes for the pipe. The writers believed that this occurred only in extreme cases, and that steels in industrial use which exhibited a division of the pipe were analogous with regard to their state of deoxidation to example No. 68 of the Committee. More complete deoxidation allowed the steel to pipe even below the solidified skin on the ingot head.

In every case, moreover, thermal insulation of the open surface of killed ingots increased the yield. The non-insulated open surface radiated heat to the surrounding space, whilst the walls of the ingot, when once they had become detached from the mould (and this took place fairly rapidly), radiated to a surface which was already hot. In consequence the velocity of the progress of crystallisation in the skin at the ingot head was of the same order as that at the walls. It might be considered then as fairly well established that the rate of lowering of the liquid level due to shrinkage depended on the shape of the ingot and chiefly on the ratio between its height and its section. In the case of tall ingots the liquid fell rapidly and the crust on the head could attain no great thickness, whilst in the case of squat ingots the columnar crystals in the crust were able to grow sufficiently rapidly to maintain contact with the liquid. The pipe was in consequence displaced towards the bottom of the ingot and this necessitated a longer crop end.

By preventing the solidification of the metal in the ingot head a larger reserve of metal was left to feed the pipe.

AUTHOR'S REPLY.

The AUTHOR, in reply, wrote that he thanked Professor Portevin and Mr. Pierard for their contribution to the discussion on his paper which was much appreciated. Broadly speaking, processes occurred during the freezing of steel not treated with silicon similar to those which he had described for silicon-treated steel under diminished pressure. There was, however, one difference which he would like to point out: The evolution of gas from mild steel not treated with silicon resulted from the reaction between carbon and oxygen (which reaction itself resulted from the decrease in

[1] Since 1926, a series of types of soundness of basic Bessemer ingots, showing diagrammatically the succession of these phenomena and appearances, had been given in the "Annexes du Cours de Métallographie à l'École Supérieure de Fonderie" (p. 200 of the 1936 edition).

temperature and progressive freezing) according to the equation $C + FeO - CO + Fe$, and from the separation of hydrogen from the melt at the freezing point. Under the prevailing conditions as to concentration the partial pressure of the carbon monoxide was greater than 1 atm., so that gas evolution was bound to occur. By hermetically sealing the mould and preventing the separation of the gas, the pressure rose to such an extent that gas evolution was inhibited. Thus in the interior of a mild-steel ingot increased pressure prevailed. Such was not the case with silicon-treated steel. Here the partial pressure of the carbon monoxide was below 1 atm., even if the temperature dropped; similar remarks applied to the hydrogen. If that were not the case, then the steel was "blown up" by the gas pressure and a porous ingot resulted. In point of fact all intermediate values of partial pressures from below 1 atm. to above 1 atm. could occur, according to the composition of the steel and its gas content. In practice it was within the power of the melter so to control the process that he obtained sound non-porous steel with a gas pressure below 1 atm. If, nevertheless, the pressure in a closed-topped ingot sank during solidification below 1 atm., and equalisation of pressure with the external atmosphere could not take place, then gas evolution and blow-holes could occur even in otherwise sound steel. That applied with equal force to steels containing 0·25–0·35% and even up to 1·5% of silicon and aluminium additions which under normal conditions should be quite sufficient to ensure a sound ingot and complete piping.

THE ATMOSPHERIC CORROSION OF GALVANISED IRON WIRE AND ITS BEARING ON SPECIFICATION TESTING.*

By C. E. RICHARDS, F.I.C. (London).

(Figs. 8 to 13 = Plates IV. to VII.)

Synopsis.

The question of specification testing is of great importance to the large user of galvanised wire. In Britain the copper sulphate dipping test (Preece test) still enjoys favour.

It is shown that the Preece test is of little value in determining the resistance of a wire to atmospheric corrosion. It discriminates unfairly against some coatings and flatters others. The predominating factor in the life of galvanised wire in a given atmosphere is the thickness of the zinc envelope, and characteristics such as the purity and ductility of this coating are of minor importance.

The lives to be expected of wires in different types of atmosphere are calculated, and estimates are given of the cash value of adequate galvanising for a typical wire structure. Savings of the order of 25% are shown for this structure, in which the cost of wire is only about 10% of the original cost of erection. The economy is due to the saving on labour costs resulting from fewer renewals.

The wide disparity between the rates of failure in industrial and rural areas is demonstrated, and the fact that under certain circumstances even bare iron patches are of little importance is shown.

Laboratory investigations have given interesting results, but have been of little help in suggesting specification tests.

A plea is made for discarding the Preece test on wires in favour of a stripping test. The ductility test as at present specified (B.S.S. 443) is useful and should be retained.

The purchase of galvanised wire by large organisations is on such a scale that the matter of exact specification assumes some importance, and it is very desirable to be able to command a test or tests which can be used to assess the true quality of the wire. The mechanical properties of the wire can be readily checked by the standard mechanical tests, but since galvanising is applied generally to increase the weather-resisting properties of the wire, some kind of chemical test would seem to be appropriate. It is, of course, out of the question to apply even greatly accelerated weathering tests for the purpose of specification testing, and perhaps the main purpose of the work described here has been to conduct a sufficiently

* Communication from the Post Office Research Station, Dollis Hill, London, received January 5, 1938.

comprehensive series of weathering tests, coupled with laboratory tests, to show what control tests, if any, are suitable for use.

This work was started in 1930, and has been mainly concerned with the type of wire purchased by the Post Office as " stay wire." At this time the quality of wire was controlled by B.S.S. 182–184 (1927), and it was being found that certain supplies of wire, whilst satisfactorily meeting the specification requirements, were giving very poor life in service.

Since the commencement of the investigation the specification position has been materially changed by the issue of B.S.S. 443–1932, in which modified test methods are described in detail.

In general it may be said that the new specification (No. 443) calls for a wire which shall be at least as heavily galvanised as that which would pass the older tests (No. 182), but which in addition must have a more ductile coating. Wire which will pass the galvanising clauses in specifications 182–184 (1927) will not necessarily pass the more stringent requirements of specification 443, one of which is a wrapping test followed by a copper sulphate dip test.

About the time when this investigation was commenced, many manufacturers of galvanised wire were actively modifying their galvanising processes with a view to providing an improved product. Exactly what standards were aimed at by the different firms is not known, but it is thought that ductility of the coat and a pleasing appearance were probably considered to be of primary importance.

The question of increasing the corrosion resistance of a galvanised wire has not in the past been quite straightforward, since there was considerable diversity of opinion as to the factors governing corrosion resistance. To take an example, it has been held in certain quarters that electrodeposited zinc will resist corrosion more than an equal thickness of ordinary galvanising spelter.[1]

The position, therefore, at the commencement of these tests can be summarised thus :

(1) There was a specification extant, but wire purchased with reference to it often gave poor service.

(2) Progressive manufacturers were improving their works practice with a view to supplying a more resistant type of wire which also had a good appearance. In the trade, however, agreement was not complete as to the best methods of achieving this end.

(3) The methods of testing in use were frequently subject to criticism.

The object of this research has been to throw light on the following points :

(*a*) The factors which must be considered when assessing the value of a galvanised coating.

(*b*) The life of galvanised wire in Britain.

(*c*) The methods of test appropriate to galvanized wire.

Both laboratory and field tests have been conducted, and will be considered separately.

Throughout this paper the various supplies of wire are identified by numbers. Some sources of supply, Nos. 1–8, are not actually known, the wires having been supplied by the Iron and Steel Wire Manufacturers' Association in connection with some other tests.

Experimental.

At the commencement of this work, supplies of wire were obtained from a representative selection of manufacturers. From time to time wires submitted by other makers have been tested, and the results of such tests that are relevant have been included in this paper. The gauges of wire under consideration are No. 8 S.W.G. and No. 14 S.W.G. of the type used for stay wires; the nominal diameters of these wires are 0·160 and 0·080 in., respectively. Some results which have been obtained on another size of wire are included as a matter of interest. As an incidental matter, the question of using stainless-steel wire in certain districts has been considered.

Laboratory Tests.

These have been directed to determining the properties of the wires, in respect of the various tests which can be applied for specification purposes.

In Table I. the results of a series of tests on all types and sizes of wire are given. The following characteristics were determined:

(1) The average thickness of coating, determined by stripping in concentrated hydrochloric acid containing 0·15% of antimonious chloride.

(2) Effect of copper sulphate dipping test on straight wires.

(3) Effect of copper sulphate dipping test on wires which had been wrapped in helices on and unwrapped from mandrels 2½, 4 and 8 times the standard diameter of the wire.

The copper sulphate dipping tests were conducted exactly in the manner described in B.S.S. 443. The No. 8 S.W.G. and the 400-lb. line wires were given 1-min. dips throughout, whilst the No. 14 S.W.G. wires in the straight form received three 1-min. dips followed by ½-min. dips to failure. The No. 14 S.W.G. wires after the mandrel wrap were given two 1-min. dips followed by ½-min. dips until failure. The figures in the Table refer to the average number of minutes during which the wires withstood the action of the solution, irrespective of the individual dip times. In columns *H*, *J*, *K* and *L* are given the proportion of the samples tested which would have passed the existing specification requirements quoted in B.S.S. 443.

In considering these results it should be pointed out that the 2½-times mandrel is not mentioned in any standard specification,

but is included here as representing the most severe condition met with in standard practice with stay wires, *i.e.*, at the "make off" of a 4-strand wire.

TABLE I.—*Coating Thickness and Behaviour in Copper Sulphate Dip Test.*

A.	B.	C.	D.	E.	F.	G.	H.	J.	K.	L.	M.
			Copper Sulphate Dip Test, Time. Min.				Wires passing Test. %.				
No. of Supply.	Gauge.	Coating. Oz. per sq. ft.	Straight.	2½-times Mandrel.	4-times Mandrel.	8-times Mandrel.	Straight.	2½-times Mandrel.	4-times Mandrel.	8-times Mandrel.	$R = C/D$
Mild-Steel Stay Wire.											
1	8	1·09	8·25	4·5	5·4	6·0	100	83	100	100	0·13
2	8	0·77	4·3	3·7	3·3	3·2	100	100	100	100	0·18
3	8	1·14	7·7	4·7	5·5	5·1	100	100	100	100	0·15
4	8	1·00	5·9	1·3	3·5	4·6	100	33	83	100	0·17
5	8	1·32	7·0	0	0	1·25	100	0	0	33	0·19
6	8	0·65	4·5	3·3	3·7	4·0	100	100	100	100	0·14
7	8	0·92	5·6	4·4	4·5	4·7	100	100	100	100	0·16
8	8	0·22	2·0	1·2	1·7	2·0	0	0	0	0	0·11
11	8	0·97	4·7	3·2	...	...	100	100	...	...	0·21
12	8	0·96	5·0	3·2	...	...	100	83	...	...	0·19
13	8	1·15	4·25	1·6	...	...	75	17	...	...	0·24
14*a*	8	0·55	4·0	...	...	...	100	...	...	...	0·14
14*b*	8	0·43	4·0	2·8	...	...	100	80	...	...	0·11
15	8	1·41	7·25	1·8	...	...	100	33	...	...	0·19
16	8	0·79	4·7	4·5	...	...	100	100	...	...	0·17
17	8	0·88	3·7	3·6	...	...	67	100	...	...	0·23
18	8	0·89	5·6	4·3	...	...	100	100	...	...	0·16
19	8	0·90	...	4·0	...	...	100	100	...	...	...
20	8	0·92	6·0	5·0	...	...	100	100	...	...	0·15
2	14	0·77	3·5	2·5	2·4	2·3	83	83	83	33	0·22
3	14	0·84	4·2	3·5	3·5	3·6	100	100	100	100	0·20
5	14	0·72	6·25	0	0	0·58	100	0	0	0	0·11
6	14	0·59	3·3	2·5	2·6	2·5	67	100	100	67	0·18
7	14	0·70	3·9	3·3	3·3	3·8	100	100	100	100	0·18
11	14	0·82	3·2	2·8	...	...	33	83	...	...	0·26
12	14	0·85	3·8	0	...	...	100	0	...	...	0·22
13	14	0·84	3·7	2·0	...	...	100	50	...	...	0·23
14	14	0·43	3·5	3·0	...	...	67	100	...	...	0·12
15*a*	14	1·04	...	...	...	...	...	...	...	...	...
15*b*	14	1·04	3·75	1·75	...	...	50	33	...	...	0·28
16	14	0·55	3·2	3·5	...	...	33	100	...	...	0·17
17	14	0·84	2·9	3·0	...	...	0	100	...	...	0·29
18	14	1·03	3·9	3·5	...	...	100	100	...	...	0·27
19	14	1·02	...	2·5	...	...	...	100	...	...	...
20	14	0·68	3·8	3·2	...	...	100	100	...	...	0·18
High-Purity Iron Wire.											
2	400-lb.	0·97	5·8	0	0	4·2	100	0	0	100	0·17
3	400-lb.	0·98	4·75	4·4	4·0	3·9	100	100	100	100	0·21
6	400-lb.	0·89	5·6	4·6	4·4	4·4	100	100	100	100	0·16
7	400-lb.	1·11	4·7	0	0	4·0	100	0	0	100	0·24

Since stay wire in use will have to withstand wrapping around an article 2½ times its own diameter there is some ground for insisting that it should be tested in just as stringent a manner. The matter does not appear, however, to be of great importance, since of the seventeen samples of wire tested at all mandrel sizes only

one of those which was satisfactory after testing with the 4-times mandrel was found to fail after wrapping on the 2½-times mandrel. The same argument may not apply in the case of fencing wire, which is generally terminated by wrapping around itself. That the mandrel test does make the requirements for wire rather more stringent is shown by the fact that of all the wires which passed the straight dipping test, nine samples failed after the use of the mandrel, whilst of the wires which passed the mandrel test satisfactorily five were unable to withstand the longer dip time required by straight wires. Out of thirty-six types of wire tested, seventeen would have been rejected by the combination of tests.

Turning now to Table I., column *M*, in which the relations between the average weight and the time during which a straight wire resisted the action of copper sulphate solution are quoted, it will be seen that there is little agreement between the relations obtained for the products of different manufacturers. If, however, wires of different types but emanating from the same factory are considered, better agreement will be found; thus, for Nos. 8 and 14 S.W.G. mild-steel stay wire and 400-lb. high-purity iron line wire, the following are the values of *R* (in the above order):

	8 Gauge.	14 Gauge.	400-lb.
No. 2 supply . . .	0·18	0·22	0·17
No. 3 supply . . .	0·15	0·20	0·21
No. 5 supply . . .	0·19	0·11	...
No. 6 supply . . .	0·14	0·18	0·16
No. 7 supply . . .	0·16	0·17	0·24
No. 11 supply . . .	0·21	0·26	
No. 12 supply . . .	0·19	0·22	
No. 13 supply . . .	0·24	0·23	
No. 14*b* supply . . .	0·11	0·12	
No. 15 supply . . .	0·19	0·28	
No. 16 supply . . .	0·17	0·17	
No. 17 supply . . .	0·23	0·29	
No. 18 supply . . .	0·16	0·27	
No. 20 supply . . .	0·15	0·18	

The above selection embraces all types of coatings including electro-galvanised wire, and it seems possible that for the product of one factory the dip number may be a roughly constant function of the average coating thickness.

Structure of the Galvanised Coatings.

The characteristics of the coatings on many of the wires (including all the types of No. 8 S.W.G. wire used for field tests) were studied by means of electrode-potential measurements and by metallographic examination.

Electrode Potential.—The measurement of the rate of change in the potential difference between galvanised iron and a reference electrode in acid solution has been made by a number of investigators (*e.g.*, Evans [2] and Britton [3]), and has been proposed as a specifica-

tion test. Evans [2] found that, using zinc as a reference electrode and a normal solution of hydrochloric acid as electrolyte, arrests were found at or about 0·27 V. in the case of hot galvanised coatings. With sherardised coatings an arrest at 0·34 V. was obtained. In the course of the present investigation similar tests have been made on the wires used for field trials, using zinc wire as the reference electrode and normal sulphuric acid as electrolyte. (Sulphuric acid was chosen as it was thought to represent more closely the acids found in rain-water.) The testing temperature was $25 \pm 0{\cdot}5°$ C. At this temperature the potential between a mild-steel wire and the

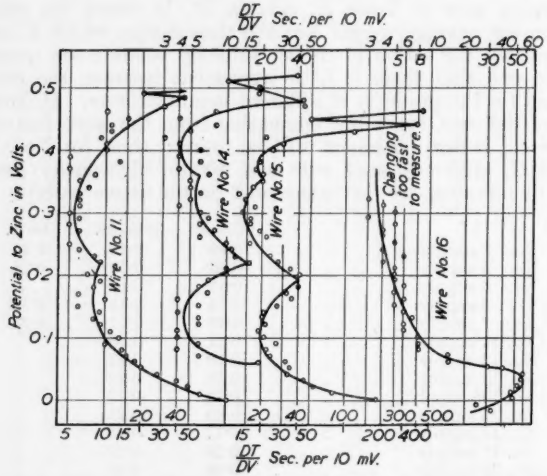

DT/DV Sec. per 10 mV.
3 4 5 10 15 30 50 20 40 3 4 6 10 20 40 60 5 8 30 50
0·5
0·4
0·3
0·2
0·1
0
Potential to Zinc in Volts.
Wire No. 11
Wire No. 14.
Wire No. 15.
Changing too fast to measure.
Wire No. 16
5 10 15 30 50 20 40 15 30 50 20 40 100 200 300 400 500
DT/DV Sec. per 10 mV.

FIG. 1.—Rate of Change of Potential of Galvanised Wires during Stripping in Sulphuric Acid.

reference zinc electrode was approximately 0·5 V. Instead of plotting the direct potential-time curves, the inverse-rate curves were constructed, *i.e.*, the times taken for the test wire to change in potential by separate increments of 10 mV. were plotted against the actual potential difference between the electrodes. Specimen curves obtained on No. 8 S.W.G. wire are shown in Fig. 1, and it will be seen that arrests occur in most cases at 0, 0·2, 0·34 and 0·47 V. The effect of the cut end of the wire can be neglected, as this was sealed by petroleum jelly. The zero arrest is, of course, due to the outer coating of substantially pure zinc, whilst the others appear to represent the alloy layers as they become uncovered. In the curves, the time base is plotted logarithmically to save space, and the effect is to shorten the appearance of the arrests. When the time is plotted

linearly the arrests can be seen more clearly. Vigouroux, Ducelliez and Bourbon [4] give a potential-composition curve for zinc-iron alloys against a zinc reference electrode in 0·05*N* zinc sulphate. In this solution iron has a potential of 0·4 V. to zinc, and the curve shows steps at 0·13, 0·18 and 0·34 V., corresponding to the alloys, $FeZn_7$, $FeZn_3$ and Fe_5Zn_2. Direct comparison between these two curves, which were taken in different solutions, does not seem possible.

In the case of wire No. 14 the potential difference reading starts at 0·06 V. This wire has no outer covering of pure zinc. On the other hand, wire No. 16, which shows an arrest only at zero, is an electrogalvanised wire.

An attempt was made to determine the relative amounts of the various alloy layers by partial stripping of the coating. To do this the wires were immersed (one at a time) in 1*N* sulphuric acid until the potential to a zinc electrode had reached 0·08 V., and the loss in weight was determined. This was followed by further stripping to 0·3 V., and then to 0·5 V. Some of the results are given in Table II.

TABLE II.—*Partial Stripping Tests.*

	Loss in Weight. Oz. per sq. ft.			Loss of Total Coating. %.		
	0–0·08 V.	0·08–0·3 V.	0·3–0·5 V.	0–0·8 V.	0·08–0·3 V.	0·3–0·5 V.
Wire No. 11	0·30	0·48	0·07	35	57	8
,, ,, 13	0·22	0·99	0·21	15	70	15
,, ,, 14	0·03	0·32	0·12	6	68	26
,, ,, 15	0·24	0·91	0·29	17	63	20
,, ,, 16	0·48	0·32	0·03	58	39	3

That these results cannot be taken as quantitatively indicating the proportions of the various constituents is shown by the figures for wire No. 16, which, being electroplated, is substantially pure zinc right down to the iron base. There is, however, some relationship between the results obtained by this stripping test and the brittleness of the coating on some of the wires. Wires Nos. 13 and 15 have distinctly more brittle coatings than the other wires tested by this method, and both these wires have a relatively heavy coat of iron-rich alloy next to the iron base, as is shown by the large loss between 0·3 and 0·5 V. Wire No. 11, also a hot-galvanised wire, has one of the most flexible coatings which have been tested. Inspection of the potential-time curves will show that No. 11 wire has only a small arrest at 0·2 V., but No. 15 has a much more pronounced one. Wire No. 13 (curve not reproduced) behaves in a similar way to No. 15.

Fig. 8 shows the behaviour of some of the No. 8 S.W.G. wires on wrapping around a mandrel $2\frac{1}{2}$ times the diameter of the wire.

Metallographic Examination.—Fig. 11 shows the microstructures of the coatings of the No. 8 S.W.G. wires which have been the subject of most of the tests. The photomicrographs are of transverse sections of the coating after polishing and etching with dilute nitric acid. The structures of the various coatings can readily be seen, and in the case of hot galvanising are very similar to one another. The different alloy phases can clearly be seen. In the case of one hot-dipped wire the outer coating of pure zinc is absent.

The metallographic examination reveals certain structural differences between the coatings of wires which will withstand wrapping without serious damage and those on which the coating cracks or flakes badly when the wire is wrapped around a small mandrel. Wires Nos. 13 and 15, which fail most severely on wrapping, both show distinct signs of impurities dispersed through the outer zinc envelope. Nos. 11 and 18, which do not suffer much on wrapping, all show a clean outer layer of zinc. Wire No. 14 is coated with a series of alloys only, no zinc sheath being visible. This wire appears to have been wiped and possibly heat-treated. The electrogalvanised wire, No. 16, has a peculiar structure, consisting of at least eight layers of varying thickness; each of these annular rings is made by one passage through the plating bath. The intermediate layers are superficial oxide films formed between successive dips.

The photomicrographs were taken in order to show typical coating structures and not relative thicknesses. With most wires the thickness varies appreciably from point to point.

Tests in Spray Chambers.

One further series of laboratory tests was made; this was conducted in the " industrial fog " spray chamber (*see* Appendix). It will be seen in the section on field tests that there appears to be some doubt as to the relative importance of the thickness and ductility of a zinc coating. To some extent these requirements conflict, since it is comparatively easy to produce a thin zinc coating which will not crack or flake visibly, but more difficult to give a wire a thick coating of zinc which will behave in the same way; it has also often been observed that zinc-coated wire fails first at points where it has been sharply bent or wrapped around a small diameter, thereby causing the coating to crack. On the other hand, it is known that when iron is definitely exposed and zinc is in contact with it, the zinc will, to some extent, protect the iron from corrosion by " sacrificial action." In doing so it is to be expected that the rate of corrosion of the zinc will be increased and also that the area over which the zinc will offer this protection will be strictly limited. In order to throw some light on this aspect of the problem, samples of galvanised wire, similar to that used in the field tests, were partly stripped of their zinc coatings by protecting one part and removing the exposed zinc by hydrochloric acid and antimony

chloride. In this way specimens were prepared having bands of galvanising interspaced with bands of plain steel. Three sets were prepared, in which the stripped bands were $\frac{1}{8}$ in., $\frac{1}{4}$ in. and $\frac{3}{8}$ in. wide and the galvanised bands $\frac{3}{4}$ in., $\frac{5}{8}$ in. and $\frac{1}{2}$ in. wide, respectively. Plain galvanised wire and completely stripped wire also were tested.

TABLE III.—*Loss in Weight and Strength in Industrial Spray Test.*

Exposure. Weeks.	Total Weight of Zinc.* Mg.	Total Loss of Weight. Mg.	Residual Zinc. Mg.	Loss in Weight on Exposure.* Oz. per sq. ft.	Residual Strength. %.
		Fully Galvanised Wire.			
0	440	0	440	...	100
3	440	162	306	0·34	98
6	432	215	240	0·46	94
9	415	342	110	0·76	98
12	415	368	80	0·82	93
		$\frac{1}{8}$-*in. Stripped Bands.*			
0	365	0	365	...	100
2	365	...	...	...	99
4	376	243	140	0·49	98
6	360	262	172	0·55	93
8	355	303	131	0·65	96
10	365	332	73	0·70	91
12	353	349	22	0·78	95
		$\frac{1}{4}$-*in. Stripped Bands.*			
0	305	0	305	...	...
2	330	143	237	0·28	100
4	330	233	106	0·45	98
6	325	268	95	0·52	92
8	320	316	65	0·62	100
10	330	321	39	0·62	96
12	335	350	25	0·66	98
		$\frac{3}{8}$-*in Stripped Bands.*			
0	230	...	230	...	...
2	230	125	200	0·26	93
4	250	206	84	0·41	98
6	238	222	35	0·46	96
8	246	258	62	0·52	98
10	238	229	25	0·47	91
12	244	304	12	0·60	100
		Completely Stripped Wire.			
0	0	0	0	0	100
2	0	70	0	0·15	91
4	0	217	0	0·46	96
6	0	421	0	0·89	96
8	0	377	0	0·79	95
10	0	529	0	1·11	88
12	0	634	0	1·33	93

* These figures have been corrected for the exposed length of the specimens, where this varies slightly from the standard 5 in.

Six samples of each kind of wire (except the fully galvanised, of which four only were used) were placed in the industrial spray chamber and samples were removed every two weeks (three weeks for the completely galvanised) and examined. Measurements of loss in weight and strength were made. Two loss-of-weight measurements were made, (*a*) after removal of rust cathodically in sodium cyanide, and (*b*) after stripping the residual zinc from the exposed portion by hydrochloric acid and antimony chloride. In this way, since the area of the galvanised coating is known in each case, the rate of penetration of the exposed iron can be calculated. The accuracy of results is, of course, dependent upon the uniformity of the original zinc coating on the wire. Complete experimental figures are given in Table III.

The loss in weight of iron without any corresponding decrease in the residual strength figure, recorded in some cases in the last column of Table III. is due to the fact that (with the exception of the initial figures for strength) all the figures apply to tests on individual samples which necessarily differed initially from one another.

The results shown in Table III., when considered in conjunction with those obtained in the field tests, demonstrate one important point, namely, that the continuity of galvanising is not in all circumstances the most important factor, but that the thickness, even when it involves a little brittleness, is more to be sought for. It must here be stressed that this test, conducted as it was in spray chambers in which the content of sulphurous gases was abnormally high, should not be regarded as universally applicable, since (as is shown later) the relative rates at which iron and zinc corrode in different atmospheres vary, the rates being more comparable in areas where the atmospheric pollution is greatest and the disparity being greatest in clean and possibly saline atmospheres. In the spray chambers the rates of attack of iron and zinc are closer than in any of the atmospheres which have been tested, and so these results should be regarded as indicating possible behaviour in industrial areas and further deductions avoided.[5]

It is, however, remarkable that with the zinc coating spaced instead of continuous, the total loss of weight of the specimens was in almost all cases less than that of either plain steel wire or galvanised wire, even with the wide spacings adopted in the tests. It can be inferred that in certain circumstances the electro-chemical protection of iron by zinc will save considerably more iron than it will cost in zinc used up, and that a considerable degree of protection is exercised at appreciable distances from the boundary of the zinc. It seems probable, however, that this type of protection will break down in circumstances such as marine exposure, when the zinc itself becomes somewhat passivified, and may therefore not be expected to protect the iron so thoroughly by electro-chemical means. This point has already been demonstrated by Evans.[2] Figs. 9 and 10

show stages of the attack on the partially stripped metal, and the relative corrosive damage which has occurred during twelve weeks' exposure.

Composition of Basis Metal and Coatings.

The compositions of the two bare wires which were used in the exposure tests and of the zinc coatings on the galvanised wires were determined and the results are given in Tables IV. and V.

TABLE IV.—*Composition of Bare Wires.*

	Wire No. 11.	Wire No. 16.
Carbon : Combined. %	0·068	0·073
Graphitic. %	...	..
Silicon. %	...	...
Copper. %	0·05	0·008
Manganese. %	0·43	0·44
Sulphur. %	0·045	0·055
Phosphorus. %	0·065	0·04
Nickel. %	0·01	0·03
Chromium. %	0·007	0·003

TABLE V.—*Composition of Galvanised Coatings.*

Wire No.	Gauge.	Zinc.* %.	Iron. %.	Aluminium. %.	Lead. %.	Cadmium. %.
11	8	96·41	3·57	0·02	...	...
11	14	97·46	2·54	<0·01	...	...
12	8	96·03	3·94	0·03	...	...
12	14	97·05	2·92	0·03	...	...
13	8	97·4	2·53	<0·10	...	...
13	14	97·6	2·30	<0·10	...	...
14*b* †	8	93·2	6·70	<0·10	...	...
14	14	94·12	5·85	0·03	...	...
15	8	93·87	4·86	0·10	0·78	0·39
15*b* ‡	14	96·79	2·83	0·08	0·30	...
16	8	99·68	0·31	0·01	...	...
16	14	99·70	0·27	0·03	...	...
17	8	95·8	4·10	<0·10	...	...
17	14	97·6	2·33	<0·10	...	...
18	8	95·51	4·49	<0·01	...	...
18	14	97·45	2·51	0·04	...	...
14*a* G.P.O.†	8	94·16	5·83	0·01	...	...
15*a* G.P.O.‡	14	96·01	3·97	0·02	...	...

* By difference. † ‡ Wires from same factory.

The analytical figures are helpful in only one or two cases, *e.g.*, wires No. 15, 8 gauge, and No. 15, 14 gauge, are both coated with a dirty-surfaced metal, and in fact the wires both needed treatment with dilute acid before they would give a reliable Preece test.

There is an unusual amount of lead in this coating. Zinc coatings containing lead are, of course, not novel, but it seems that British galvanisers as a whole do not favour their use on wire. This metal was, of course, sought for in the coatings of other wires.

B.N.F.M.R.A. Stripping Test.

Since this work was started, the British Non-Ferrous Metals Research Association have developed a new type of stripping test. This test (here called the B.N.F. test) is designed to measure the minimum thickness of the zinc.

The essence of the test (which has been described by Britton [3]) is to strip the coating from the wire by electrolysis, using a predetermined and specified quantity of electricity, and then to examine the wire for spots of bare iron by immersing it for a short time in dilute copper sulphate solution. The coating is specified by the length of time it should take for current at a certain density to bare the iron.

TABLE VI.—*Results of B.N.F. and Preece Tests.*

Wire. No.	Gauge.	Average Coating. Oz. per sq. ft.	Minimum Coating (I.). Oz. per sq. ft.	Minimum Coating (II.). Oz. per sq. ft.	Preece Test (Straight). Min.
11	8	0·97	0·81	0·77	4·7
12	8	0·96	0·71	0·67	5·0
14*a*	8	0·55	0·43	...	4·0
16	8	0·79	0·73	...	4·7
11	14	0·93	0·86	0·85	3·2
12	14	0·85	0·79	0·76	3·8
15*a*	14	1·04	0·94	...	No satisfactory figure obtained
16	14	0·55	0·47	...	3·2

Minimum coating (I.) refers to the coating thickness determined exactly as recommended by Britton.

Minimum coating (II.) is the value obtained by setting the current approximately and using an ampere-minute meter.

A modification which has been introduced at Dollis Hill is to replace the ammeter in the circuit by an ampere-minute meter. By doing this the necessity for strict control of the current is avoided, and an approximate setting only need be made. This alteration is not of much consequence in laboratory testing, when a comparatively uniform voltage is obtainable from batteries or the d.-c. mains, but will make a material difference in the case of works tests, where the mains voltage may vary over a considerable range.

Most of the wires which were still available at the time when this method was published were tested, and the results are given in Table VI., where figures obtained by both modifications of the

method are quoted. For reference, the Preece test values and the average weights of the coatings are also given.

Field Tests.

In recent times it has been more and more realised that the use of empirical tests for corrosion resistance is liable to lead to entirely false conclusions in the study of corrosion problems. This is particularly noticeable when the effects of coatings of different compositions are being compared, such as zinc and cadmium, but it is apparent to some extent when different varieties of zinc are under comparison. Thus, for example, it has been shown by many observers that different types even of hot-galvanising will dissolve at appreciably different rates in copper sulphate solution.[6, 7]

This criticism also applies to accelerated corrosion tests such as the various spray tests which are employed, and in the present state of knowledge the use of the field test as the ultimate criterion is still necessary.

In the present case field tests were conducted at fifteen stations throughout Britain, the actual districts having been chosen to represent almost all the different types of atmosphere encountered where overhead telephone-plant construction is possible. The one condition missing is that of an uncontaminated atmosphere on the sea coast. A station at Aberystwyth was intended to provide this, but the results obtained are not those which would be expected in a pure sea-coast atmosphere, and wires returned from this station gave a distinct reaction for sulphates, which are derived from smoke, but little or no chloride could be found.

The following stations were selected :

(1) *Manufacturing districts of various kinds.*
Widnes, Warrington, St. Helens, Hanley, Sheffield, Birmingham, Maryland (London, E.).

(2) *Urban areas.*
Taplow, Aberdeen, Dollis Hill (London, N.W.2), Shepherd's Bush (London, W.).

(3) *Rural and suburban.*
West Coast : Aberystwyth.
East and West Midlands : Spalding, Marlborough.
Lake District : Plumpton.

The details of the test are as follows : A number of stout wooden frames were made, each capable of holding ninety wires, 8 in. long. The wires were supported horizontally in a single layer, 1 in. apart. The frames were constructed so that a lid and bottom could be screwed into position for transport purposes and readily removed at the exposure station. A photograph of the actual frames exposed at Dollis Hill is reproduced in Fig. 12.

The tests cover Nos. 8 and 14 S.W.G. wires from eight different manufacturers, these being Nos. 11–18 inclusive. In addition to this, wire taken from actual contract deliveries to B.S.S. 183 was drawn from stores, and two varieties of ungalvanised wire (*i.e.*, the plain mild-steel wire from which the galvanised wire was produced) were obtained from manufacturers 11 and 16. The No. 14 S.W.G. wire from stores was found to have been supplied by manufacturer 13 and the No. 8 S.W.G. wire by manufacturer 14.

The whole test has run for $5\frac{1}{2}$ years, and 5-year tests have been completed on all the wires enumerated, with the exception of the ungalvanised ones, which have been tested only to $2\frac{1}{2}$ years. At the start of the test each frame was loaded with the following wire samples:

G.P.O. Stores No.	8	S.W.G.		10	wires
,, ,, ,,	14	,,		10	,,
Maker No. 11 ,,	8	,,		10	,,
,, ,, ,, ,,	14	,,		10	,,
,, ,, 12 ,,	8	,,		10	,,
,, ,, ,, ,,	14	,,		10	,,
,, ,, 16 ,,	8	,,		10	,,
,, ,, ,, ,,	14	,,		10	,,
,, ,, 11 ,,	8	,,	Plain	5	,,
,, ,, 16 ,,	8	,,	,,	5	,,
			Total	90	

Each wire before insertion in the frame was cleaned in benzene and weighed, and $1\frac{1}{2}$ in. at each end was protected by dipping in hot petroleum jelly. Before placing the wires in position in the frames all the sockets were stuffed with petroleum jelly. The relative position of the wires in the frame was a matter of chance. After fitting the frames they were closed and despatched to their various exposure stations. There the tops and bottoms were unscrewed, and the wires were exposed out-of-doors for six months (March to September), after which they were returned to headquarters for examination. This consisted of a general examination of the state of the wires and the removal for test purposes of one wire from each group mentioned above. The ten empty spaces in the frame were filled by one No. 8 S.W.G. wire and one No. 14 S.W.G. wire from the supplies obtained from manufacturers 13, 14, 15, 17 and 18. After $2\frac{1}{2}$ years, when all the ungalvanised wires had been removed from the frame, only eight places became available each half year, and for this reason replacements by wires from supply 18 were discontinued. Thus in $5\frac{1}{2}$ years results have been obtained on wires of two gauges and from nine sources.

In addition to this main body of tests, one or two subsidiary ones have been made, and will be described separately.

The results of the tests have been analysed and are given mainly

in tabular form below; some of the more important are shown graphically.

The exact method of determining the various results will now be described.

Loss in Weight and Strength of Galvanised Wires.

As mentioned above, before assembly in the frames, all the wires were washed in pure benzene, dried and weighed. They were then greased so that a central test length of 5 in. only was exposed to weathering. The weathered samples on return to headquarters were wiped free from grease with a soft cloth, and completely degreased either in hot benzene or (in later cases) in carbon tetrachloride vapour. The corrosion products were then removed by hot distilled water (early tests having proved that this method was completely successful so long as the zinc was not discoloured by rust). No insoluble zinc salts were detected, the products left on the wires being in all cases principally zinc sulphate, crystals of which could frequently be distinguished. No basic or other chlorides were detected, even on the wires from Aberystwyth.* The wires were then inspected, and any showing appreciable signs of rust were cleaned by making them cathodes in an electrolytic cell, using 10% sodium cyanide as electrolyte and passing current at 15 amp. per sq. ft. for about 20 min.[3] The cleaned wires were then weighed and the loss in weight was noted. The wires which had been stripped in cyanide were then broken in a tensile testing machine, and the breaking load was recorded. (The early tests had proved that until the zinc coating was destroyed and rusting of the iron had taken place no appreciable loss in strength occurred.)

Fig. 13 shows the states of two supplies of No. 8 S.W.G. wire after exposure at Sheffield for periods up to 5 years. It will be observed that the wire having the thinner coating (0·43 oz. per sq. ft.) actually started rusting in less than 12 months, whereas the wire with the heavy coating (1·4 oz. per sq. ft.) lasted about 3 years before showing rust.

Plain Mild-Steel Wires.

These were degreased as above and cathodically cleaned in sodium cyanide. Loss-in-weight and loss-in-strength measurements were made as for the galvanised wires.

* For this reason it is considered that the open-sea atmosphere test is not covered by the tests, as inspection of several fencing wires and pole stays of galvanised iron along the sea coast, on coastguard and local lines remote from anything but small villages, has shown that the wires are encrusted with an insoluble white zinc salt which is presumably basic zinc chloride. This is presumably the same state as the galvanised sheets from the Scilly Islands described by Evans.[2] A similar product is formed when galvanised articles are exposed in salt spray chambers using 3% sodium chloride spray.

From these measurements information under the following heads was obtained :

(1) The rate of loss of zinc from the surface of typical galvanised wires in various types of atmosphere.

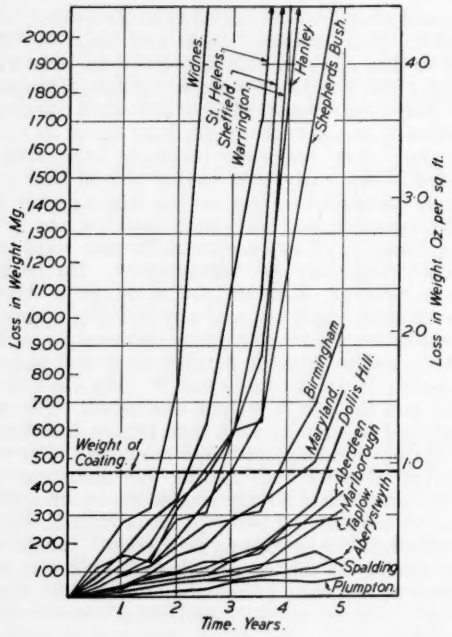


FIG. 2.—Rate of Loss in Weight of Wire, Supply No. 11, in different places.

(2) The rate of decay of the underlying steel base.

(3) Variations in the rate of loss of zinc between different types of wire.

(4) The approximate life to be expected from any given description of wire in any atmosphere.

Headings (1) and (2) will be taken together, since the varying ratios between the rates of attack of the two metals in different situations are of some interest. Some idea of the different rates can also be obtained by inspecting Figs. 2 and 3, which show loss-in-weight results for two different types of wire exposed at the same time.

Relative Rates at which Zinc and Iron Corrode in Different Atmospheres.

From the loss-in-weight figures obtained for the specimens originally exposed the comparative rates at which the zinc envelope and the underlying iron base corrode at different places have been calculated. In working out these figures the annual losses in weight of those 8 S.W.G. wires which had not lost more than 60%

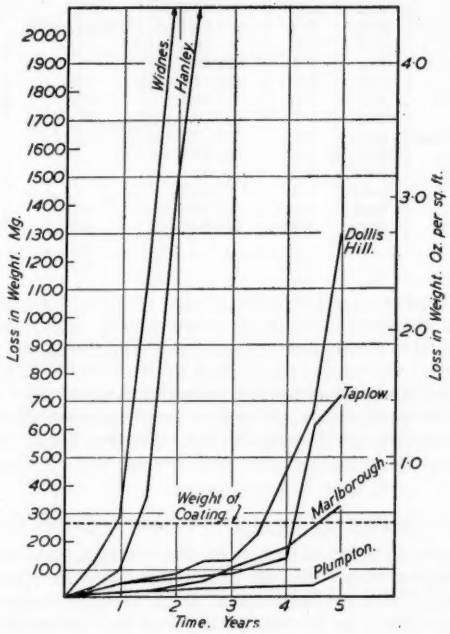


FIG. 3.—Rate of Loss in Weight of Wire, Supply No. 14*a*, in different places.

of the weight of the zinc coating were used as the basis of the rates of loss of zinc. No figures were used when the wire had shown actual rusting. The corrosion rate taken for mild steel was in each case the average rate for the two varieties of plain wire under test, Nos. 11 and 16. Losses are given in ounces per square foot per annum and the surface area assumed is the nominal original surface exposed to the atmosphere, *i.e.*, πdl, where d is the nominal diameter of the wire, 0·16 in., and l is the exposed length. The rates are given in Table VII.

TABLE VII.—*Relative Corrosion Rates in Different Atmospheres.*

Place of Exposure.	Rate of Loss. Oz. per sq. ft. per annum.			Rate of Loss for Type of Area. Oz. per sq. ft. per annum.		
	Zinc.	Iron.	Ratio.	Zinc.	Iron.	Ratio.
St. Helens .	0·34	5·05	1 : 14·8			
Widnes . .	0·56	5·05	1 : 9·0			
Warrington .	0·24	5·72	1 : 23·8			
Sheffield. .	0·26	3·6	1 : 13·8	0·27	4·25	1 : 15·7
Maryland .	0·17	2·7	1 : 15·9			
Birmingham .	0·11	2·7	1 : 24·6			
Hanley . .	0·21	4·9	1 : 15·9			
Taplow . .	0·11	2·1	1 : 19·1			
Aberdeen .	0·08	1·6	1 : 20·0	0·14	1·96	1 : 14·0
Shepherd's Bush	0·28	2·46	1 : 8·8			
Dollis Hill .	0·11	1·7	1 : 15·5			
Marlborough .	0·06	1·4	1 : 23·4			
Plumpton .	0·04	1·4	1 : 35·0	0·05	1·42	1 : 28·4
Spalding .	0·06	1·5	1 : 25·0			
Aberystwyth .	0·04	1·37	1 : 34·3			

The relative rates of corrosion of zinc and iron vary considerably in different districts, becoming more nearly comparable as the pollution of the atmosphere increases. The rates are roughly in agreement with the figures mentioned by Hudson.[9] It is interesting to record that in the spray testing chamber in which an "industrial" atmosphere is maintained, there is a concentration of 20 parts per million of sulphur dioxide in the air. In this spray chamber the relative rates of corrosion of zinc and iron are as 1 : 2 approximately.

Variations in the Rate of Loss of Zinc between Different Types of Wire.

There have, in point of fact, been two series of tests on galvanised wire, the former being that in which the 6-month specimens were exposed from March to September, 1931, and the 5-year specimens from March, 1931, to March, 1936, and the latter in which the 6-month specimens were exposed from March to September, 1936, and the 5-year specimens from September, 1931, till September, 1936. Determinations of relative rates of loss of zinc between wires of different type have been made for the former set of wires only, as these embraced a wider selection of types. The No. 8 S.W.G. wires only were considered. The rates of loss have all been compared with the rate of loss of wire 14*a*, which is a wiped wire, and has been given the value 100 in each case. The results are given in Table VIII.

Taking averages of these sets of figures it will be seen that wire No. 11 loses zinc at 1·18 times, No. 12 at 1·21 times and No. 16 at 1·29 times the rate of the wire which was taken as standard.

TABLE VIII.—*Variations in Rate of Loss of Zinc from Different Types of Wire.*

Station.	½ Year.	1 Year.	1½ Years.	2 Years.	2½ Years.	3 Years.	3½ Years.
			Wire No. 11.				
Taplow . .	146	94	105	96	109	164	...
Marlborough .	130	106	110	143	102	81	180
St. Helens .	123	129	135	...	...	...	...
Birmingham .	143	91	98	100	...	...	...
Dollis Hill .	144	89	133	112	83	129	...
			Wire No. 12.				
Taplow . .	154	106	126	115	108	164	...
Marlborough .	120	72	...	127	92	120	228
St. Helens .	135	142	138	...	...	...	...
Birmingham .	129	94	108	107	...	...	...
Dollis Hill .	...	93	84	124	92	127	...
			Wire No. 16.				
Taplow . .	110	118	110	125	123	170	...
Marlborough .	230	88	107	150	100	89	169
St. Helens .	148	168	145	...	...	...	...
Birmingham .	138	104	112	122	...	...	...
Dollis Hill .	...	102	60	155	107	170	...

The Rate of Decay of the Underlying Steel Base.

As stated above, coils of mild-steel wire, No. 8 S.W.G., exactly as used for galvanising, were obtained from manufacturers 11 and 16. Samples of each of these wires were exposed alongside the galvanised

TABLE IX.—*Rate of Decay of Steel Base.*

Station.	Loss of Strength, per Annum. %.	
	Wire from Maker No. 11.	Wire from Maker No. 16.
St. Helens . . .	15·1	22·4
Widnes	17·6	21·4
Warrington . . .	14·6	21·5
Sheffield	13·4	15·5
Maryland . . .	10·6	11·2
Birmingham . . .	10·9	13·1
Hanley	17·2	14·9
Taplow	8·3	10·7
Aberdeen . . .	7·3	7·8
Shepherd's Bush . .	8·4	10·2
Dollis Hill . . .	6·0	8·1
Marlborough . . .	6·7	7·4
Plumpton . . .	6·8	6·4
Spalding	5·3	7·5
Aberystwyth . . .	5·4	7·6

wires and were tested in the same manner. The two types of wire did not corrode at the same rate; this was hardly to be expected, but the difference in the rates was larger than was anticipated. In the case of unprotected wires, the loss in strength is the important factor, and detailed results are given in Table IX. This point is considered further below.

Brittleness of the Coating.

A point which has not yet been referred to, so far as exposure tests are concerned, is the effect of brittleness of the coating on the life of the wire. It is generally noticed that a wire which has been severely handled first shows signs of rust on the damaged portions, and it is maintained that a brittle galvanised coating is of less use than a flexible one, as after bending, it exposes part of the base beneath. It can freely be admitted that, given two coatings equal in weight, the more flexible one will almost certainly be the better. Imagine, however, two coatings, one brittle but weighing 1 oz. per sq. ft., and the other flexible and weighing only 0·6 oz. per sq. ft., which is then the better coating? In the case of a coating such as nickel, which is electronegative to iron, the answer is comparatively simple. With an electropositive coating such as zinc, which affords sacrificial protection, the answer is not so clear.

In order to obtain some light on this point both laboratory and field tests were made. The laboratory tests have already been described. Two sets of field tests were also made. The first one consisted of exposing at Dollis Hill a set of partially stripped wire specimens similar to those used in the laboratory tests. The results which are now available are given in Table X.

TABLE X.—*Decay of Steel Base. Effect of Partial Stripping.*

	Breaking Strength. Lb.					
	Original.	½ Year.	1 Year.	1½ Years.	2 Years.	2½ Years.
⅛-in. bands	1745	1755	1755	...	1730	1690
¼-in. bands		1762	1704	...	1640	1680
⅜-in. bands		1678	1722	...	1720	1615

It should be noted that the figures in the Table refer to individual samples, whereas the original breaking load quoted was the average of a large number of samples cut from this coil of wire.

The rate of loss of strength of bare steel at Dollis Hill is about 7% per annum. The original breaking weight of this supply of wire was 1745 lb., so that if the zinc had exerted no protective action the strength after 2½ years' exposure should be not more than

1450lb. As the above figures show, it averages 1660 lb., thus indicating that even with such large bare areas as are represented here the zinc is exerting a very marked protective action. It may be anticipated that this will be even greater when the sizes of the pores through to the bare metal are much smaller, *i.e.*, when a *little* cracking occurs in the coating on bending.

The second series of field tests was made on a number of wire helices which had been wrapped around a mandrel $2\frac{1}{2}$ times the diameter of the wire. After removal from the mandrel the helices were stretched a little to separate the turns. The specimens were all cleaned and weighed, as for the straight specimens, and then exposed at Widnes. Breaking-strength tests were not made, since any loss in strength due to corrosion was entirely masked by the work-hardening, which was not constant. Loss-in-weight measurements only were made, and the complete results are given in Table XI.

TABLE XI.

Supply.	Loss of Weight, mg., after—					Coating. Oz. per sq. ft.	Weight of Coating per Test Length. Mg.
	0·5 Year, Summer.	1 Year, Winter.	1·5 Years, Summer.	2 Years, Winter.	2·5 Years, Summer.		
No. 8 S.W.G. Wire. Surface exposed, 10·5 sq. in.							
11	103	547	571	911	1205	0·97	2000
12	99	566	592	1352	1992	0·96	1980
13 *	56	434	469	932	1097	1·15	2370
14	70	943	3608	8213	10211	0·43	890
15 *	81	324	448	982	1126	1·41	2910
16	89	631	716	955	1914	0·79	1630
17	90	592	638	935	Missing	0·88	1820
18	103	475	584	866	1446	0·89	1830
No. 14 S.W.G. Wire. Surface exposed, 3·3 sq. in.							
11	44	239	298	502	894	0·82	530
12 †	31	257	446	1257	1692	0·85	550
13	39	239	278	585	1152	0·83	540
14	32	455	1373	2193	3165	0·43	280
15 *	37	208	981	521	827	1·04	680
16	39	243	718	2340	3450	0·55	360
17	40	245	284	519	1283	0·84	550
18	44	245	281	596	744	1·03	670

* Brittle coatings, which cracked badly, but did not flake from the surface.

† Particularly brittle coating which flaked in large pieces from the surface.

From these results it is clear that, based on loss-of-weight tests, a thick coating even when brittle is superior to a thin coat. From the part of the Table referring to 8 gauge wires it appears that neither of the brittle coatings is sufficiently bad to allow severe

attack of the base metal, since, as the same area of zinc is exposed in each case, any attack of the base metal would be additive, and the same applies to any increase in the rate of loss of zinc by sacrificial action. In this part of the Table there was no wire which flaked badly, although Nos. 13 and 15 cracked rather severely. The superiority of the heavy coatings over the light ones is amply demonstrated. In the second part of the Table, however, there is one wire (No. 12) on which the coating is so brittle as to flake badly, pieces of the base metal about $\frac{1}{4}$ in. long being frequently exposed. The other brittle wire (No. 15), although cracking severely, did not flake. Here the severe flaking of No. 12 wire has had its effect on the loss in weight (though possibly some of this loss may be due to the actual falling away of some of the flakes), whereas the cracked, but not flaked, No. 15 behaves similarly to the wires which retain their coating more or less intact.

Reference may here be made to the copper sulphate dipping tests conducted on the wires after wrapping on and unwrapping from mandrels, in which wire No. 12 (14 S.W.G.) was found to fail on the first dip after it had been wrapped on the mandrel. Observations on this particular type of wire when exposed in helices at Dollis Hill showed that, even though large areas of the iron were visible, it was actually several months before any rust was observed.

The figures given in Table XI. seem to prove that, even when severe work has to be done on the wire after manufacture, to increase the flexibility of the coating at the expense of the thickness is very unsound practice, unless the heavier coating is likely to be particularly brittle and to flake off in large pieces.

These remarks should strictly be applied only to the case of wires which are erected in industrial, urban and suburban areas, where there will in the normal course be sufficient acid in the atmosphere to give a soluble zinc product. In the case of absolutely rural or marine exposure, a continuous zinc envelope may be more important.

Additional Field Tests on Wires Nos. 13, 14, 15, 17 *and* 18.

Although, from the tests already described, the results of field exposure for all the above wires were available as soon as the full $5\frac{1}{2}$ years' testing was complete, an additional test was run at Dollis Hill to give information on those wires (Nos. 13, 14, 15, 17 and 18) which were not included in the first exposures. These wires were exposed in July, 1931, and examined half-yearly. For the Dollis Hill Station, therefore, duplicate information is available for the rate of weathering of most of the eight types of No. 8 S.W.G. wire. These results are given in full in Table XII.

It will be seen that, although there is some discrepancy in the earlier parts of the Table, due possibly to different weather conditions, by the time 5 years' exposure had been reached most of the galvanised wires were corroding at substantially the same rate, and

TABLE XII.—*Dollis Hill Tests. Additional Tests.*

Wire No.	Loss of Weight, mg., after—										Coating.	
	6 Months.	1 Year.	1½ Years.	2 Years.	2½ Years.	3 Years.	3½ Years.	4 Years.	4½ Years.	5 Years.	Oz. per sq. ft.	Mg. per Test Length.
11	13	48	151	90	106	...	177	249	338	603	0·97	460
12	23	50	100	99	118	163	284	492	337	472	0·96	455
13	22	44	73	98	99	144	182	440	543	424	1·15	550
13	...	137	261	218	205	363	335	475	305	463	1·15	550
14	13	42	71	88	100	261	940	1540	2191	2938	0·43	205
14	31	169	198	184	97	533	575	1202	1842	2524	0·43	205
15	16	69	77	270	100	255	330	423	...	453	1·41	670
15	...	...	...	...	...	247	158	217	343	440	1·41	670
16	56	55	71	124	137	204	203	279	299	465	0·79	380
17	...	141	208	272	290	307	311	288	495	755	0·88	420
17	21	53	86	121	121	170	251	355	395	540	0·88	420
18	20	51	81	118	132	188	255	524	382	570	0·89	425
18	...	...	...	...	...	310	321	360	412	683	0·89	425

the only one to fail seriously is that which had a very light coating of zinc (0·43 oz. per sq. ft.). The other wires are just approaching or have only just passed the point at which the galvanising has been completely stripped. The blanks in the Table are mainly due to supplies of wire of particular kinds running short, as it was not thought desirable to obtain further supplies and include them in the tests.

Austenitic Stainless Steel.

In view of the extremely high rate at which galvanised wire of all kinds was found to fail in areas such as Widnes, Sheffield and Hanley, it was thought that the behaviour of austenitic stainless steel would be worth investigating. This material is now very well known and contains approximately 18% of chromium and 8% of nickel, the rest being iron. This alloy, in the fully softened condition, has about twice the strength of the mild steel used for making galvanised stay wire, so a thinner wire will perform the same duty. The ultimate strengths required by the British Standard Specification for Nos. 8 and 14 S.W.G. stay wires are 1200 and 300 lb., respectively, whereas the breaking loads of Nos. 11 and 17 S.W.G. austenitic stainless steel wire were 1170 and 286 lb. Tests on this type of wire were confined to two stations, Dollis Hill and Widnes. At the latter place both straight and helical specimens underwent exposure. The results are given in Table XIII.

It will be seen that even under the severely corrosive atmospheric conditions at Widnes the stainless-steel wire loses very little weight or strength, the loss in weight of a No. 8 S.W.G. wire being 90 mg. in 3·5 years or about 0·2% per annum, whilst the No. 17 S.W.G. wire loses about 1% per annum. The losses in strength are, for the period under review (3·5 years), within the limits of experimental error (which includes variability of material) for all but the No. 17

TABLE XIII.—*Austenitic Stainless Steel. Test Results.*

At Dollis Hill.

Gauge.	After— 6 Months.	1 Year.	1·5 Years.	2 Years.	2·5 Years.	3 Years.	3·5 Years.	
				Loss in Weight. Mg.				
8	0	13	7	5	8	9	14	
11	0	1	6	4	7	9	8	
14	0	1	6	7	12	6	8	
17	0	1	7	3	5	5	7	
				Breaking Strength. Lb.				Original Strength. Lb.
8	2161	2120	...	2185	...	2195	2175	2194
11	1220	1225	...	1234	...	1232	1225	1250
14	555	554	...	568	...	563	564	587
17	302	281	...	286	...	279	279	286

At Widnes.

Gauge.	After— 6 Months.	1 Year.	1·5 Years.	2 Years.	2·5 Years.	3 Years.	3·5 Years.	
				Loss in Weight. Mg.				
8	12	40	50	50	48	89	90	
11	10	13	38	43	50	46	65	
14	8	29	33	42	63	56	62	
17	6	1	23	37	25	51	58	
11	143	135	141	140	...	...	...	Helices
14	39	99	71	74	114	...	...	Helices
				Breaking Strength. Lb.				
8	2195	2225	2175	2200	2156	2150	2187	
11	1216	1200	1156	1185	1166	1150	1192	
14	580	573	549	564	552	564	555	
17	275	269	265	259	253	255	253	

S.W.G. wire; the latter lost about 8% in strength in 3½ years. In the circumstances it is not possible to give a reasoned estimate of the life of the heavier gauges of wire, but it seems probable that the life of the 11 S.W.G. will be at least 10–15 years, which is about five times as long as any galvanised wire can be expected to stand.

Summary of the Results of the Field Tests.

The various loss-in-weight and loss-in-strength figures having been determined for the exposed wires, the results may be summarised in the following manner.

As previously stated, a wire is deemed to have failed when its strength has dropped to 75% of its original value. If corrosion took place in a perfectly uniform manner this point would also be when the wire had lost 25% of its original weight (allowing for the fact that about 1% of the original weight is zinc, which has a very low tensile strength). Since, however, corrosion does not proceed in a uniform manner, it is certain that the loss in strength will be greater than the loss in weight. The difference between the two will depend on the particular steel used for making the wire.

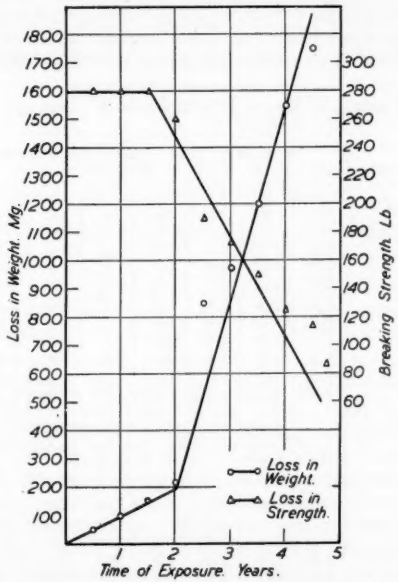


FIG. 4.—Rate of Loss in Weight and Loss in Strength of Wire, Supply No. 11, 14 S.W.G., at St. Helens.

If the figures for loss in weight are plotted on a time base it will be seen (Fig. 4) that they form a curve which essentially consists of two straight lines. The early part of the curve, which has only a gentle slope, corresponds to the time when the zinc is still intact and is corroding at a constant rate. The upper portion, also straight but much steeper, relates to the time when all the zinc has disappeared and the steel base itself is rusting. Between these two portions is an intermediate one gradually increasing in steepness, when the zinc is gradually failing to protect the iron. By extrapolation of the two straight parts, an intersection is obtained which

may be taken as the point at which the zinc fails to exert its protective action on the iron, and thus represents the effective life of the zinc. This point has been determined for wires in the more corrosive atmospheres. The time taken for the wires to reach 75% of their original weight has also been obtained by interpolation on the same curves, whilst from the breaking-strength curves the life of the wires until the strength drops to 75% has been obtained. From curves of this type the effective life and effective thickness of the galvanising on each type of wire has been determined for eight situations, mostly industrial in nature. It has not been possible to estimate these factors for suburban and rural conditions, as most of the wires have not failed sufficiently to make a reliable estimate possible. The results are given in Table XIV.

TABLE XIV.—*Effective Lives of Coatings.*

Station.	No. 8 S.W.G. Wires. Effective Life of Coatings, Years, on Wires Nos.—								
	11.	12.	13.	14*a*.	14*b*.	15.	16.	17.	18.
Widnes	1·9	1·7	2·2	1·0	1·0	2·4	1·7	1·7	...
Warrington	3·3	3·0	3·2	1·5	1·2	3·6	2·6	2·9	3·0
St. Helens	2·3	2·0	2·3	1·2	0·8	3·4	1·9	1·9	...
Hanley	3·1	2·9	2·1	1·4	...	2·4	2·5	...	...
Sheffield	3·0	2·5	2·6	1·4	...	3·4	2·3	2·4	...
Birmingham	4·0	4·0	3·6	2·6	...	3·6	3·9	3·4	...
Maryland	3·8	3·3	3·6	2·4	2·3	4·2	2·9	3·6	3·7
Shepherd's Bush	2·6	3·0	3·0	1·8	...	3·9	2·9	2·6	...
Average	3·00	2·80	2·83	1·66	1·32	3·36	2·59	2·64	3·35

Station.	No. 14 S.W.G. Wires. Effective Life of Coatings, Years, on Wires Nos.—								
	11.	12.	13.	14.	15*a*.	15*b*.	16.	17.	18.
Widnes	1·1	1·1	1·3	0·8	1·6	1·6	0·8	...	...
Warrington	2·9	2·6	2·3	1·0	2·9	2·6	1·6	2·2	2·9
St. Helens	2·0	1·6	1·9	1·0	2·6	2·4	1·1	1·5	...
Hanley	2·6	2·1	...	...	2·5	1·9	1·3	...	...
Sheffield	2·4	1·9	1·7	...	2·3	2·3	1·2	1·6	...
Birmingham	3·8	3·4	3·3	1·7	3·5	3·1	2·25	2·75	...
Maryland	4·2	3·0	2·9	2·4	3·6	3·9	2·4	3·3	3·7
Shepherd's Bush	3·1	2·9	2·4	...	2·95	2·8	2·2	2·4	...
Average	2·77	2·33	2·15	1·38	2·75	2·58	1·61	2·29	3·3

In Table XV. are listed the effective lives of the coatings on the various wires per ounce of coating per square foot.

The effective thicknesses of the galvanising on the various wires are tabulated in Table XVI.

For a number of these wires additional figures are available for exposures at Taplow, Aberdeen and Dollis Hill. These results do

TABLE XV.—*Effective Lives of Coatings per Ounce per Square Foot.*

Station.	No. 8 S.W.G. Wires. Effective Life, Years per Oz. per sq. ft., of Coatings on Wires Nos.—								
	11.	12.	13.	14*a*.	14*b*.	15.	16.	17.	18.
Widnes . .	1·96	1·77	1·91	1·81	2·33	1·70	2·15	1·93	...
Warrington . .	3·40	3·12	2·78	2·73	2·79	2·81	3·29	3·30	...
St. Helens . .	2·37	2·08	2·0	2·18	1·86	2·65	2·41	2·16	...
Hanley . .	3·20	3·02	1·83	2·54	...	1·87	3·17	...	...
Sheffield . .	3·09	2·61	2·26	2·54	...	2·65	2·91	2·73	...
Birmingham .	4·12	4·17	3·14	4·73	...	2·81	4·94	3·87	...
Maryland . .	3·92	3·44	3·14	4·37	5·35	3·54	3·67	4·09	4·15
Shepherd's Bush .	2·68	3·12	2·61	3·27	...	3·04	3·67	2·95	...

Station.	No. 14 S.W.G. Wires. Effective Life, Years per Oz. per sq. ft., of Coatings on Wires Nos.—							
	11.	12.	13.	14.	15*a*.	15*b*.	16.	17.
Widnes . .	1·18	1·29	...	...	1·54	1·54	1·45	...
Warrington . .	3·12	3·06	2·77	2·33	2·79	2·50	2·91	2·62
St. Helens . .	2·15	1·88	2·29	2·33	2·50	2·31	2·00	1·79
Hanley . .	2·80	2·47	...	...	2·40	1·83	2·37	...
Sheffield . .	2·58	2·24	2·05	...	2·21	2·21	2·18	1·91
Birmingham .	4·09	4·00	3·98	3·96	3·37	2·98	4·09	3·28
Maryland . .	4·52	3·53	3·50	5·58	3·46	3·75	4·36	3·93
Shepherd's Bush .	3·78	3·42	2·89	...	2·84	2·69	4·0	2·86

not, however, affect the averages given above to an appreciable extent, as will be seen from Table XVII., and for comparative purposes the figures in the foregoing Tables will be used.

As stated earlier, No. 8 S.W.G. steel wires from two supplies (Nos. 11 and 16) were exposed in the ungalvanised state. They were exposed for periods of up to 2½ years, and were tested in the same way as the galvanised wires. From the detailed results the average rates of loss of strength given in Table XVIII. have been calculated.

From the loss-in-strength graphs plotted for the galvanised wires, the following rates of loss were determined for 8 and 14 S.W.G. wires. The figures are based in all cases on the average tensile strength of the wires at the beginning of the tests. These results show fair agreement (Table XIX.).

From the loss-in-weight tests it has been possible to determine not only the effective weight of the galvanising, but also the annual loss at the various stations. The average figures for the various types of area are given in Table XX. It should be noted that in this Table account has been taken of *all* the varieties of wire exposed, whereas in Table VII. only those wires which were first exposed are considered. Agreement exists in the average results to two significant figures, though appreciable differences were found in the detailed results.

TABLE XVI.—*Effective Thickness of Galvanising.*

Station.	No. 8 S.W.G. Wires. Effective Thickness, Oz. per sq. ft., of Galvanising on Wires Nos.—								
	11.	12.	13.	14*a*.	14*b*.	15.	16.	17.	18.
Widnes	0·84	0·71	0·70	0·34	...	1·02	0·76	0·72	...
Warrington	0·76	0·80	0·56	0·29	0·24	1·2	0·67	0·64	...
St. Helens	0·84	0·76	0·88	0·34	0·36	1·4	0·76	0·84	...
Hanley	0·76	0·76	0·72	0·32	...	0·82	0·67	...	...
Sheffield	0·84	...	0·76	0·34	...	1·1	0·67	0·76	...
Birmingham	0·74	0·68	0·80	0·36	...	0·80	0·68	0·68	...
Maryland	0·76	0·70	0·60	0·40	0·36	...	0·61	0·64	0·68
Shepherd's Bush	0·60	0·60	0·80	0·38	...	1·2	0·68	0·70	...
Average	0·77	0·72	0·73	0·35	0·32	1·06	0·69	0·71	0·68

Station.	No. 14 S.W.G. Wires. Effective Thickness, Oz. per sq. ft., of Galvanising on Wires Nos.—							
	11.	12.	13.	14.	15*a*.	15*b*.	16.	17.
Widnes	0·67	0·63	...	...	0·97	0·78	0·42	...
Warrington	0·75	0·59	0·53	0·22	0·84	0·56	0·42	0·56
St. Helens	0·80	0·59	0·90	0·40	0·97	0·84	0·42	0·60
Hanley	0·75	0·50	...	...	0·84	0·78	0·38	...
Sheffield	0·80	0·55	0·60	...	0·88	0·80	0·38	0·59
Birmingham	0·72	0·62	0·70	0·40	0·76	0·80	0·44	0·60
Maryland	0·84	0·64	0·55	0·48	0·76	0·82	0·42	0·57
Shepherd's Bush	0·85	0·72	0·90	...	0·72	0·70	0·46	0·62
Average	0·77	0·61	0·70	0·38	0·86	0·76	0·40	0·59

TABLE XVII.—*Effect of including Results from Three Additional Stations on Average Values for Thickness of Galvanising.*

Wire No.	Gauge.	Effective Thickness, Oz. per sq. ft.	
		Average for Limited Number of Specimens.	Average for all Specimens Available.
14*a*	8	0·33	0·33
14*b*	8	0·32	0·35
13	14	0·70	0·70
14	14	0·38	0·39
16	14	0·40	0·41
17	14	0·59	0·61

TABLE XVIII.—*Loss in Strength of Ungalvanised Wires.*

Type of Area.	Annual Loss of Tensile Strength. %.		
	Supply No. 11.	Supply No. 16.	Average.
Industrial	14·1	17·1	15·6
Urban	7·2	9·2	8·2
Rural and suburban	6·1	7·2	6·6

TABLE XIX.—*Loss in Strength of Galvanised Wires.*

Type of Area.	Annual Loss of Tensile Strength. %.					
	1st Exposure.		Replacements.		Average.	
	8 S.W.G.	14 S.W.G.	8 S.W.G.	14 S.W.G.	8 S.W.G.	14 S.W.G.
Industrial .	15·1	28·7	13·1	22·1	14·1	25·4
Urban . .	10·7	22·0	12·2	16·5	11·5	17·2

TABLE XX.—*Loss in Weight of Galvanised Wires.*

Type of Area.	Loss in Weight. Oz. per sq. ft. per year.	
	No. 8 S.W.G.	No. 14 S.W.G.
Widnes	0·46	0·47
Industrial	0·27	0·31
Urban	0·14	0·16
Rural and suburban . .	0·05	0·06

From these results it is possible to calculate the probable life of a galvanised wire.

The average effective thickness of the galvanising on the wires which have been tested was 75% of the average thickness as measured by chemical stripping for No. 8 S.W.G. wires and 80% of the average thickness for No. 14 S.W.G. wires (*see* Table XVI.). For calculation purposes take the lower of these two figures, then the life of a wire will be the life of the coating plus the time taken for the iron or steel base to rust until it reaches 75% of its original strength. This can be set down thus :—

for No. 8 S.W.G. wires

$$\begin{cases} = \dfrac{0{\cdot}75t}{0{\cdot}46} + 1{\cdot}3 \text{ in Widnes.} \\ = \dfrac{0{\cdot}75t}{0{\cdot}27} + 1{\cdot}6 \text{ in industrial areas.} \\ = \dfrac{0{\cdot}75t}{0{\cdot}14} + 3{\cdot}0 \text{ in urban areas.} \\ = \dfrac{0{\cdot}75t}{0{\cdot}05} + 3{\cdot}8 \text{ in rural areas.} \end{cases}$$

where l = life in years
t = thickness of galvanising in oz. per sq. ft.

The above equations reduce to

$$\begin{aligned} l \text{ (Widnes)} &= 1{\cdot}3 + 1{\cdot}63t. \\ l \text{ (industrial)} &= 1{\cdot}6 + 2{\cdot}78t. \\ l \text{ (urban)} &= 3{\cdot}0 + 5{\cdot}36t. \\ l \text{ (rural)} &= 3{\cdot}8 + 15t. \end{aligned}$$

For 14 S.W.G. wire the following approximate figures can be given :

$$l \text{ (Widnes)} = 0{\cdot}9 + 1{\cdot}57t.$$
$$l \text{ (industrial)} = 1{\cdot}0 + 2{\cdot}42t.$$
$$l \text{ (urban)} = 1{\cdot}3 + 4{\cdot}69t.$$

These functions for No. 8 S.W.G. wires are graphed in Fig. 5, in which are also marked some of the actual lives of specimens that have been recorded. Only a few typical ones can be given, or the graph would be too confused.

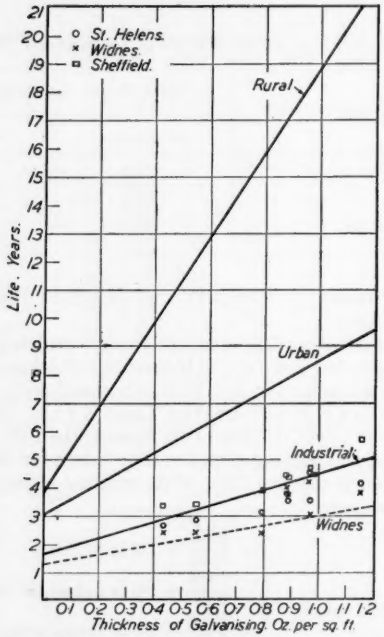


FIG. 5.—Relation between Life of Wire and Thickness of Galvanising. No. 8 S.W.G. wire.

From Table XVIII. it will be seen that there is a slight but noticeable difference in the rates at which the bare 8 gauge wires Nos. 11 and 16 corrode. Another feature which was observed during the tests was that the steel base of wire No. 12 corroded fairly consistently more slowly than the average. A copper determination was made on this wire and it was found to contain 0·15%, whereas No. 11, which corroded at an average rate, contained

0·05%, and No. 16, which corroded at rather above the average rate, contained only 0·008%.

The usual limits of coating thickness which are to be found on No. 8 S.W.G. wire made to pass B.S.S. 443 are 0·5 and about 1·2 oz. per sq. ft. Assuming that the iron base is the same in each case, the lives to be expected of wires coated with these amounts of zinc are :

Industrial areas :	3·0 and 4·9 years.
Urban areas :	5·7 and 9·4 years.
Rural and suburban areas :	11·3 and 21·8 years.

It will be seen that the additional zinc is responsible for a very marked increase in the life of the wire, the figures varying from nearly 60% to nearly 100% for the three types of area.

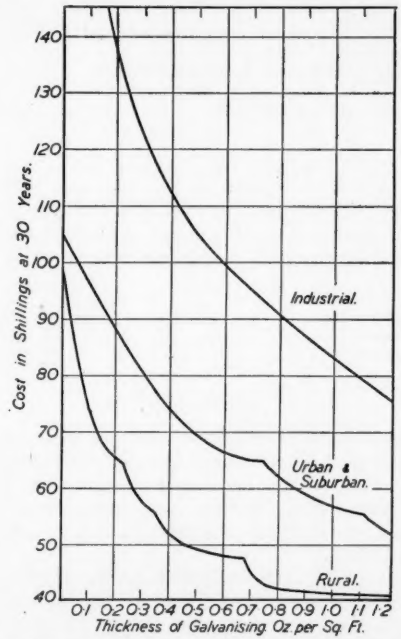


FIG. 6.—Relation between Thickness of Galvanising and Cost of Erecting and Maintaining a Pole Stay for Thirty Years.

From these data it is possible to calculate fairly accurately the cash value of the zinc coating on the wire for any given structure. An example has been worked out for the cost of erecting and main-

taining a stay to a small telegraph pole for 30 years, assuming that 8 S.W.G. wire is used and all the parts except the wire are sufficiently rust-resisting to last for 30 years without renewal. The total cost of the original erection is 12·3*s*., of which the wire itself costs 1·2*s*. Each renewal costs 4·7*s*., and the value of the recovered scrap is practically nothing. In order to get a true comparison of the cost of stays with different grades of wire, all the costs must carry interest charges. In the present example costs have been worked out as capital charges, allowing $3\frac{1}{2}\%$ compound interest on all expenditure and transferring all expense to the end of the 30 years.

An example of the method of working out the costs will make the matter clear. Consider a wire having a life of 12 years:

Cost of original erection, 12·33*s*.	
+ $3\frac{1}{2}\%$ compound interest for 30 years . . .	34·7*s*.
Cost of 1st renewal, 4·71*s*.	
+ $3\frac{1}{2}\%$ compound interest for 18 years . . .	8·7*s*.
Cost of 2nd renewal, 4·71*s*.	
+ $3\frac{1}{2}\%$ compound interest for 6 years . . .	5·8*s*.
Total cost at end of 30 years.	49·2*s*.

In Fig. 6 graphs are given showing how the cost of erecting and maintaining a pole stay varies with the thickness of the galvanising. From these curves it will be seen that by increasing the thickness of the galvanising from 0·5 to 1·2 oz. per sq. ft. the following savings can be achieved (transferring all payments to the end of the 30 years):

Industrial areas	£1	9	0 or 28%
Urban areas		17	0 or 25%
Rural areas		8	0 or 16%

Discussion.

Laboratory tests in themselves have not given a great deal of help on the subject of specifications for wire, though some interesting light on the cause of the behaviour of wire has been obtained. Considered together with the field tests, however, it seems possible now to define the qualities desirable in a wire and to suggest a rational specification.

Taking first of all the copper sulphate dipping test (Preece test), it has been shown that there is no essential relationship between the dip time or the number of dips which a wire will withstand and the thickness of the galvanising; the relation of the thickness of a galvanising (oz. per sq. ft.) to the dip time (min.) varies from 0·11 to 0·29. If, however, the products of each factory are considered separately, there is a reasonably close agreement between the relations observed for the three gauges of wire used in the tests, and if, as the outcome of this and other work, the specifica-

tion is changed, so that the weight of coating becomes the requirement instead of the ability to withstand a certain number of copper sulphate dips, the control tests in the works can still reasonably be made by the copper sulphate method, provided that a factor, suitable to the factory in question, be used. It seems improbable that this constant relationship will extend over a wide range of gauges.

With regard to the use of the copper sulphate dip test after wrapping on and unwrapping from mandrels, in the case of telephone stay wire there seems to be no point in pressing for a more stringent test than that at present included in B.S.S. 443. This condition may not hold for wire intended for other purposes.

The electrode potential tests and the partial stripping tests, although interesting in that they show that there is a relationship between the brittleness of the coating and the thickness of one of the alloy layers, appear to be useless for control purposes. Metallographic examination also gives little hope of utility except as a means of scientific investigation of the structures of the various coatings. The metallographic method of thickness measurement was not tried.

The composition of the coatings on some of the wires is of interest. In all of them a certain amount of iron was found. Some of this iron is probably derived from the base wires, for although antimony chloride was used in the stripping acid, it is certain that a little attack of the underlying iron took place. The extent of this attack is indicated by the iron figures for wire No. 16 which was electro-galvanised. It may therefore be assumed that the iron contents quoted in Table V. are about 0·3–0·5% high.

From the field tests the following points have become evident :

(*a*) The zinc coatings on all types of wire corrode at approximately the same rate.

(*b*) The life of a wire is determined principally by the thickness of the galvanising.

(*c*) The "effective thickness" of the galvanising is a practically constant function of the average thickness. This will be discussed more fully below.

(*d*) The rate of attack of the zinc varies enormously in different districts.

(*e*) The rate of stripping of zinc during exposure is greater on No. 14 S.W.G. than on No. 8 S.W.G. wire.

One of the most striking results of this series of tests has been the demonstration that the Preece test (copper sulphate dipping test) is of little value in assessing the corrosion-resisting properties of a galvanised wire, and the equally convincing demonstration that either of the two stripping tests already described will give a reasonably accurate idea of the value of the galvanised coating. The relative values of the three tests given have been reduced to

numerical indices which have been called "reliability factors." The method of calculating the reliability factors is as follows:

From the Tables already given, the relevant details for two types of wire of the same gauge, and which have been exposed together are taken, *e.g.*:

Wires Nos. 11, 8 gauge, and 14*a*, 8 gauge, exposed at Widnes:

	11/8.	14*a*/8.	
Effective life of coating	1·9	1·0	(1)
Total thickness of coating	0·97	0·55	(2)
B.N.F. „ „ „	0·81	0·43	(3)
Preece test (time in min. to failure)	4·7	4·0	(4)

From these figures can be calculated the ratios between factors (1) and (2), (1) and (3), and (1) and (4) for each wire:

	11/8.	14*a*/8.	
$\frac{\text{Effective life of coating}}{\text{Total thickness}}$	= 1·96	1·81	(5)
$\frac{\text{Effective life of coating}}{\text{B.N.F. thickness}}$	= 2·35	2·3	(6)
$\frac{\text{Effective life of coating}}{\text{Preece test values}}$	= 0·404	0·25	(7)

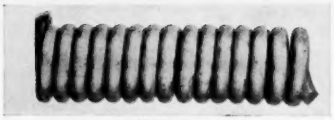
For complete reliability the factors calculated in any one way should be the same, so if the factor for No. 11 wire is divided by the factor for No. 14*a* wire, the result should be unity, and the amount by which it differs from unity will be an indication of the unreliability of the test.

Thus, taking wire 14*a* as the standard wire, the reliability factors for the three methods in this example are: 1·08, 1·03 and 1·62.

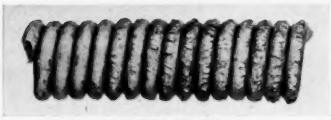
This series of reliability factors has been calculated for all the places for which a sufficient number of results have been available to make the averages reliable. The averaged results for all available stations are given in Table XXI. These results are also shown graphically in Fig. 7.

In order to obtain these figures it has been necessary to use certain of the wires as standards, these appearing in the Table as unity in each case. The B.N.F. thickness test could not be applied to all the wires, as some of these were not available when this test was published. In Fig. 7 the order of the specimens has been changed so that the graphs can be compared more easily. It will be obvious from these graphs that either of the stripping tests described will give a much closer evaluation of the corrosion resistance of a galvanised wire than will the copper sulphate dipping test.

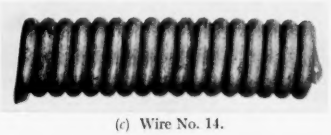
As stated above, the original object of the tests was to compare



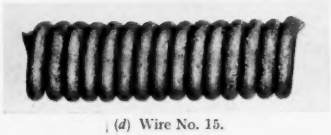
(*a*) Wire No. 11.



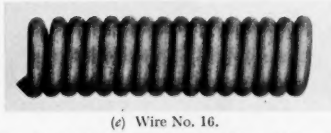
(*b*) Wire No. 13.



(*c*) Wire No. 14.



(*d*) Wire No. 15.



(*e*) Wire No. 16.

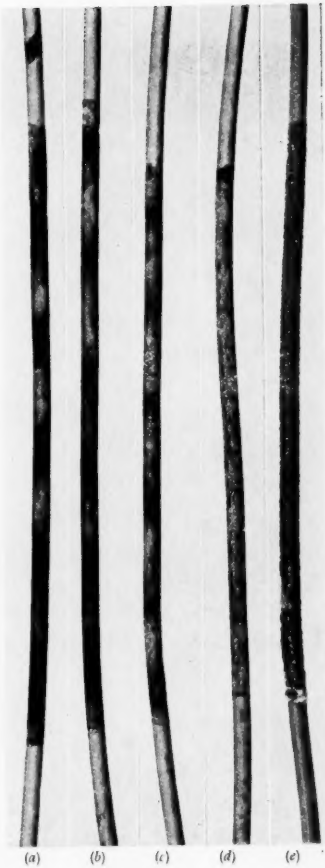
FIG. 8.—No. 8 S.W.G. Galvanised Wires Wrapped around 0·4-in. Mandrel.

(*a*) 1 Day.

(*b*) 1 Day.

(*c*) 2 Weeks.

FIG. 9.—Stripped Band of Corroding Wire Tested in Spray Chamber. × 2.



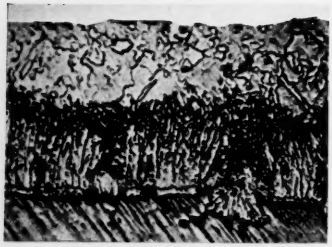
(*a*) (*b*) (*c*) (*d*) (*e*)

(*a*) $\frac{3}{8}$-in. bands.
(*b*) $\frac{1}{4}$-in. bands.
(*c*) $\frac{1}{8}$-in. bands.
(*d*) Fully galvanised.
(*e*) Completely stripped.

FIG. 10.—Wires Exposed Twelve Weeks in Spray Chamber.

[*Richards.*

[*To face p.* 160 P.

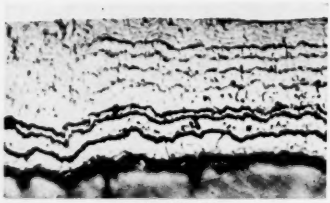


(*a*) Wire No. 11.

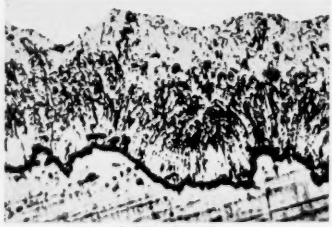
(*b*) Wire No. 13.

(*c*) Wire No 14.

(*d*) Wire No. 15.



(*e*) Wire No. 16.



(*f*) Wire No. 18.

FIG. 11.—The Microstructures of Coatings of No. 8 S.W.G. Wires. Transverse sections after polishing and etching with dilute nitric acid. × 1000 (reduced to two-thirds linear in reproduction).

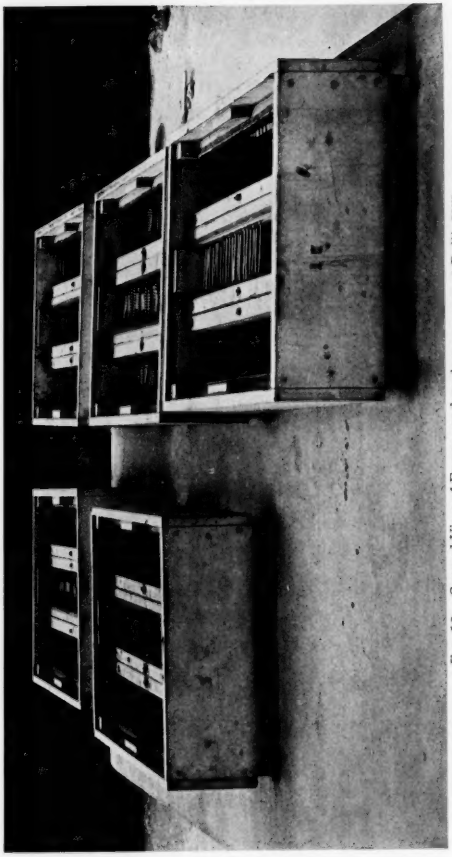
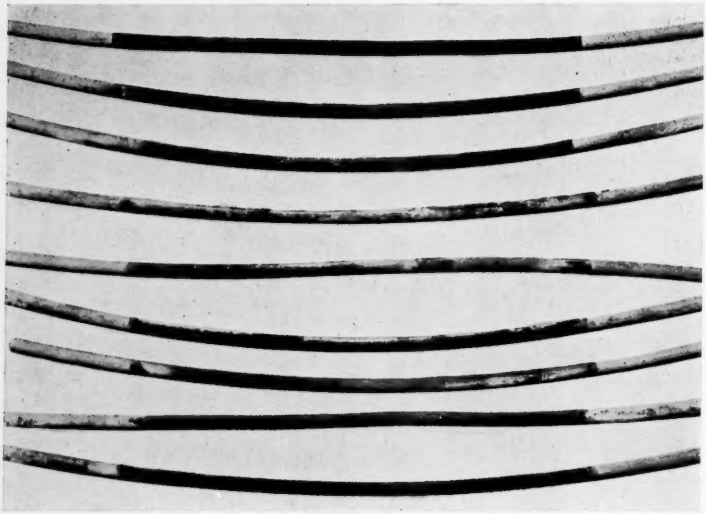
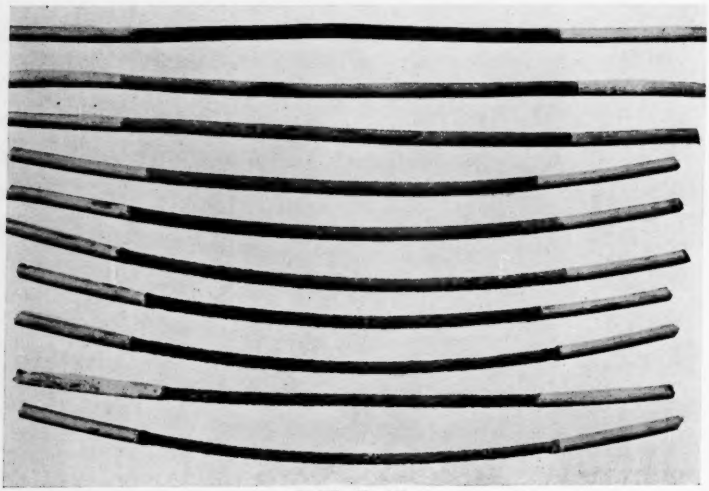


FIG. 12.—General View of Frames undergoing exposure at Dollis Hill.



(*a*) Wire No. 15.



(*b*) Wire No. 14*b*.

FIG. 13.—Wires after Exposure at Sheffield for Periods of from six months to five years. Approximately half-size.

[*Richards.*

[*To face p.* 161 P.

the value of different kinds of galvanising. The results have produced a rather broader type of comparison than was at first envisaged. There is no strikingly corrosion-resistant kind of

TABLE XXI.—"*Reliability Factors.*"

8 S.W.G. Wire No.:	11.	12.	13.	14*a*.	14*b*.	15.	16.	17.
Average thickness .	1·06	0·99	0·95	1·0	1·14	1·0	1·10	1·09
B.N.F. thickness .	0·99	1·06	...	1·0	...	...	0·97	...
Preece test . .	1·59	1·38	1·44	1·0	0·70	1·0	1·35	1·44

14 S.W.G. Wire No.:	11.	12.	13.	14.	15*a*.	15*b*.	16.	17.
Average thickness .	1·04	0·92	1·06	1·19	0·95	1·0	1·0	0·99
B.N.F. thickness .	0·95	0·87	...	...	1·14	...	1·0	...
Preece test . .	1·73	1·27	0·85	0·53	1·54	1·0	1·0	1·03

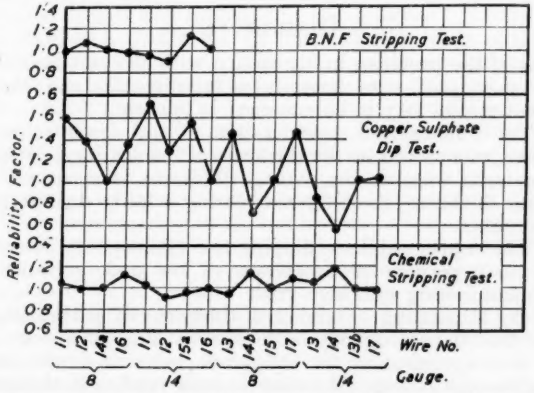


FIG. 7.—Comparison of Reliability of Methods of Testing Galvanised Wire.

galvanising; all types finish corroding at very similar rates. Therefore, other things being equal, the heaviest practicable coating of zinc is to be aimed at.

In Fig. 6 it is shown that by increasing the thickness of the galvanising from 0·5 oz. per sq. ft., which is about the smallest amount of galvanising that can be made to pass the present copper sulphate dipping test, to 1·2 oz. per sq. ft., which approaches the thickest galvanising that appears to be commercially available, savings of the order of 23% can be achieved. Inspection of these curves will show that two of them flatten at about 0·9 oz. per sq.

ft., whereas the third is still fairly steep at this point. If, therefore, instead of obtaining wire coated with 1·2 oz. per sq. ft. of zinc, a thinner coating of (say) 0·95 oz. per sq. ft. is used, the savings compared with wire coated with 0·5 oz. per sq. ft. will be :

Industrial areas	19%
Urban areas	17%
Rural areas	14%

or an average saving of 17%.

By stipulating about 0·95 oz. per sq. ft. for the coating on No. 8 S.W.G. wire, it seems probable that most manufacturers could supply at little, if any, extra cost, and users could effect an appreciable saving. It is unlikely that any wire galvanised to this thickness should show signs of brittleness owing to the coating being too heavy, besides which there are indications that discontinuity of coating may not be so serious as is generally believed. The use of stainless-steel wire in areas where the corrosion rate is very high is a possibility which should not be overlooked.

Conclusions.

Some of the problems in connection with the purchase of satisfactory galvanised wire have been investigated, and the most important results may be summarised as follows :

(1) The fundamental consideration in the specification for a galvanised wire should be the thickness of the coating. It seems to be immaterial whether the average thickness is measured or the minimum thickness, these figures bearing a fairly definite relation to one another.

(2) The copper sulphate dipping test (Preece test) is not satisfactory, as it permits the acceptance of low-grade galvanised wire on an equal footing with high-grade wire.

(3) By stipulating a minimum thickness of galvanising, substantial financial saving may be achieved at negligible cost.

(4) Any specification for high-grade galvanised wire intended for outdoor exposure should include a clause relating to the minimum thickness of zinc.

Appendix.—*Corrosion Spray Chambers.*

The corrosion spray chambers to which reference is made in the main body of this paper consist of a battery of three chambers, only one of which has been actually used in connection with this work. The construction of each one is similar, and a single description will suffice.

The chamber consists of a rectangular cupboard built of teak and glass. The top and bottom are of teak; two of the side walls are plain glass windows, the other two being double glass doors. The

teak portions were finished inside by treatment with a solution of paraffin wax in carbon tetrachloride, applied warm.

There are four vertical spindles running right through the chamber, of austenitic stainless steel (18% chromium, 8% nickel), running loosely in bushes of the same metal. Along the tops of the three chambers runs an angle-iron framework carrying line shafting running in plain bearings and with flexible joints. This is used to rotate the above-mentioned vertical spindles, the drive being through two mitre wheels. The spindles rotate about six times per minute. Specimens are carried on teak arms which can be clipped on to the spindles. The mode of attaching the specimens varies with the particular type, some being suspended, and others—for example, wires—resting in holes which have been filled with petroleum jelly.

The conditions in this cabinet have been made to resemble industrial conditions as nearly as possible. A fine mist of distilled water is produced by a scent-spray device at the top of the chamber. This is operated by air at 10 lb. per sq. in. pressure, and is so arranged that only the fine particles of mist get into the atmosphere, the larger ones being caught and returned to the reservoir. At the bottom of the chamber is a small gas jet which burns 3 cu. ft. of a specially enriched coal gas in 8 hr. The gas is enriched with carbon bisulphide vapour by a by-pass arrangement, which has been set to supply sufficient vapour to keep the sulphur content of the atmosphere equivalent to 20 parts of SO_2 per million. This is about twenty times as bad as the worst conditions found in large industrial towns.

The spray and gas pollution are only operated for 8 hr. each day. For the remaining 16 hr. and over the week-end the doors are opened and the specimens are allowed to dry. Before starting the spray each morning the specimens are washed down for 5 min. with distilled water from a paint-spraying pistol, using an air pressure of about 30 lb. per sq. in. It is hoped in this manner to simulate as nearly as possible the conditions in industrial cities and at the same time to speed up the corrosion somewhat, and it will be seen from the paper that the relative corrosion rates of iron and zinc are worse in these chambers than in any exposed situations, but that, in general, as the atmospheric pollution becomes greater, so the relative rates of corrosion approach one another.

Acknowledgments.

The author is indebted to Sir George Lee, Engineer-in-Chief, G.P.O., for permission to publish this paper, and to many of his colleagues at Dollis Hill for advice and assistance, without which it would have been impossible to complete the work.

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(9) HUDSON : *Journal of the Institute of Metals*, 1935, vol. 56, p. 91.

DISCUSSION.

Dr. U. R. EVANS (Cambridge) remarked that it gave him very great pleasure to open the discussion on the paper, which, he felt, described a really outstanding research. It had definitely settled one point which had been the cause of much discussion, namely, whether zinc should be applied thickly or sparingly; Mr. Richards showed that it should be put on thickly. Some years ago it was not uncommon to hear the opinion expressed by practical men (and personally he thought that it was at that time a reasonable opinion): "If you are galvanising a rigid piece of iron or steel, put on as much zinc as it will take; but, in dealing with a wire which is going to be sharply bent or tied into knots, if you put on too much zinc, the covering will crack, and then where will your protection be?" To this Mr. Richards now replied "The protection will still be there, or at least most of it." Mr. Richards certainly stated that it was better to have a thick unbroken coat than a thick broken coat, but he showed that it was better to have a thick broken coat than a thin coat whether broken or otherwise. Mr. Richards had shown that the thick broken coats would give electrolytic protection to the exposed iron, and it was surprising to find the distance and the length of time over which that sacrificial protection would operate.

His research served to bring out the superiority of using an anodic metal as a coat if there was any risk of discontinuities. If reference were made to Fig. 4, for example, it would be noticed that at St. Helens, a corrosive atmosphere, the galvanised wire lost no strength for 1½ years; as long as any zinc was left at all, the steel remained almost uncorroded; and as the steel was the cause of the strength, the strength remained unimpaired for that considerable period. If, in such a case, the coating had consisted of any cathodic metal and if it had been broken at any one place, there would have been corrosion of the iron, leading to local thinning and probably rapid loss of strength. In every case where there was any risk of cracking, therefore, it was advisable to use an anodic metal.

The sacrificial principle, however, must not be carried too far. Some of the remarks made some years ago about the advantages of a metal highly anodic to the basis would, if accepted literally, lead one to use coatings of potassium or sodium. Clearly, if one wished for maximum life, one should use a metal which would be just anodic enough to give protection at the widest discontinuity which was likely to occur. Only zinc came into consideration at the moment for many purposes, but some years ago he had found that aluminium would give cathodic protection to the exposed steel in some environments, but not all, and that if protection were given at all by aluminium, it would last longer than that given by zinc, because the current flow was smaller and the anodic attack on the aluminium was slower.

If one could be sure of the absence of discontinuities, it was better to use a material which would be attacked as little as possible, and that usually meant a material cathodic to steel. Thus, speaking generally, *either* a continuous, cathodic non-corrodible covering should be used, *or* (where continuity could not be obtained) a covering which was just sufficiently anodic to give the sacrificial protection required.

For a long time he had felt that every sort of coating ought to be tested not merely in the intact condition, but also with definite discontinuities, in order to see what happened at such points. In a paper which he had published ten years ago, and which Mr. Richards had quoted, he had tested a number of metallic coverings on steel, and in most of the tests definite discontinuities were intentionally made on the specimens by bending, cutting or scratching; it was found that in some instances protection was given at the discontinuities, whilst in others it was not. In subsequent researches on paint coats by himself and his collaborators, especially Mr. S. C. Britton and Mr. K. G. Lewis, scratches were engraved through the paint coats, exposing bare steel; it was found that certain paints would only protect when they were continuous, but that others would protect at the discontinuities—a very valuable property. Mr. Richards had gone very much further, because, instead of making little narrow scratches through the coat, he had removed it over very broad bands, and it was surprising to find the large amount of protection which remained. The old idea that those coverings were essentially waterproofing processes was being more and more modified; it was clear that, in many cases at any rate, the electrochemical action between the covering and basis metal was all-important.

Commander G. K. Rylands (Warrington) joined with Dr. Evans in congratulating Mr. Richards on a very admirable piece of research. A research of the character in question had been needed by the wire trade for a very long time. It was of a character which it was probably impossible for any wire manufacturer to do himself, lacking the access to a wide variety of samples from different makers and not possessing the facilities for making the exposure in various localities. One of the most remarkable things in the paper was the variation of life in different localities, and that was thrown into very bold relief. Those concerned in the trade had been conscious of it for a long time, and particularly with regard to wires for export. For instance, in Australia and New Zealand a very much better life was obtained from a galvanised coat than if it were employed in the neighbourhood of Glasgow. The paper was interesting as demonstrating the magnitude of the differences which were found.

Mr. Richards had dealt with impurities and gave an analysis of the coats of some of the wires, and the percentage of iron and lead. It would be interesting to know, however, whether Mr. Richards had

considered the other impurities and their effect on the life of coats. There seemed to be evidence to indicate that certain other impurities in galvanised coats did restrict their life, perhaps not so much in atmospheric corrosion as in intermittent sea-water corrosion, for example.

With regard to the thickness of the coat, other things being equal, it must be obvious that the thicker the coat put on the longer it would last, and it did seem that perhaps in recent years the question of ductility had been rather over-stressed. Ten years or more ago, specifications called for a wrapping test round a mandrel ten times the diameter of the wire tested, and in other cases twelve times the diameter, and in those days there was sometimes difficulty in getting the wires to stand that test. Efforts were made some years ago to improve matters, and his own firm found in the case of barbed wire that the barbs always used to rust more quickly than the line wire. One would see a very nice fence, with the line wires looking perfectly good, but the barbs all red with rust. That was one of the reasons why they had been very keen to improve the ductility. Considerable success had been achieved, but it was possible that there had been a tendency to go too far, and perhaps sacrifice some of the thickness of the coat merely for the sake of getting improved ductility. He thought that the existing British standard ductility test specification was adequate, and insured a sound coat without going to extremes. It seemed a pity when one was going to bend a wire in only one place, to make a joint or a splice on stay wire, to reduce the coat on the whole length of the wire for the sake of obtaining perfect ductility at the joint. Even if there was slight cracking at the joint, he imagined it would be possible to cover it with a good dab of hot bitumen or bitumastic paint, which would protect it for a long time.

Dr. J. C. HUDSON (Birmingham) said he had read the paper with particular interest, because he was one of the comparatively few people who had done work of a similar kind, and had exposed wires to corrosion tests in various places. Perhaps the main contribution that he could make to the discussion was to state that he was glad to find that the results of the author's experiments were in entire agreement with those obtained in the work for which he himself had been responsible, in the case both of ordinary bare steel and of zinc. In the former case, without going into very great detail, the figures given by the author in Table IX. for the corrosion of the steel base were equivalent to corrosion rates varying from about 0·002 in. of metal per annum at Spalding, the least corrosive place, to about 0·007 in. per year at Widnes. In recent tests of the Corrosion Committee,[1] the rate of corrosion of 10 S.W.G. mild-steel wire was

[1] Fifth Report of the Corrosion Committee, *Iron and Steel Institute, Special Report No.* 21, pp. 249–265.

found to be 0·007 in. per annum in the industrial atmosphere of Sheffield and about 0·002 in. per year in the less polluted atmospheres of Calshot and Farnborough. It would be seen that the two sets of figures were in good agreement, and, in view of his failure to obtain the desired marine conditions at Aberystwyth, the author would be interested to note that appreciably less corrosion of bare steel wires occurred at Calshot, where the atmosphere was marine, than at Farnborough, where the atmosphere was almost rural.

Again, in the case of the galvanised wires, the figures given by the author for the rate of loss of zinc varied from about 0·56 oz. per sq. ft. per annum at Widnes to 0·04 oz. per sq. ft. per annum at Aberystwyth. In the work of the Corrosion Committee (*loc. cit.*, Table XXXI., p. 68), the values for plates, which corroded rather less rapidly than wires, had been observed to vary from 0·39 oz. per sq. ft. per annum at Sheffield down to 0·053 oz. per sq. ft. per annum at Farnborough. Incidentally, the corresponding figure for Calshot was 0·065 oz. per sq. ft. per annum, so that, in contradistinction to the bare steel wire referred to above, a galvanised wire might be expected to corrode rather more rapidly at Calshot than at Farnborough. The agreement between the two sets of figures was again reasonably good, and it was clear, therefore, that anyone interested in the question of the corrosion of wires could take the data obtained either by Mr. Richards, whose paper referred specifically to galvanised wire, or by the Corrosion Committee, and use them to calculate how long their wires were going to last. It was obvious, of course, that local conditions, such as proximity to a chimney stack, would affect the lives considerably, but the figures obtained should enable anyone practically interested in galvanised wire to make reasonably adequate forecasts of their effective lives under given conditions.

The author's observation that the rate of stripping of zinc during exposure was greater on 14 S.W.G. wire than on 8 S.W.G. wire was in agreement with the observations of other workers that a thin wire corroded more rapidly than a thick one. For example, he (Dr. Hudson) had found this to be the case for copper wires, the equivalent rate of corrosion of high-conductivity copper wire, as determined by observations of the loss in breaking load, being about 30% greater for 70 lb. per mile wire than for 150 lb. per mile wire.[1] It would be of interest to add that the recent work of the Corrosion Committee, to which he had already referred, had shown that this also held true for steel. Thus, in the case of atmospheric exposure tests on bare steel wire, the average corrosion rate over 5 years at Farnborough and Calshot was 0·0016 in. per annum for 3½ S.W.G. wire (0·238 in. dia.), whereas the corresponding rate for 10 S.W.G. wire (0·127 in dia.) was 0·0020 in. per annum. In another series of tests at Sheffield University, the rate of corrosion

[1] *Journal of the Institute of Metals*, 1935, vol. 56, p. 100.

of 10 S.W.G. wire over 2 years' exposure was 0·0068 in. per annum, as compared with a value of 0·0083 in. per annum for 16 S.W.G. wire (0·063 in. dia.).

He gathered from the paper that Mr. Richards' two main conclusions were first of all that the behaviour of a zinc coating on steel depended essentially on its thickness, irrespective of the method of deposition. There was a good deal of evidence in the literature in favour of that statement, but, having surveyed that literature and discussed the matter with some of his technical friends in the industry, he would advise members not to accept that statement as quite final, particularly in cases where the coating was reduced below a certain limiting thickness. In his opinion, the subject still required further investigation, and he hoped that one of the functions of the Protective Coatings Sub-Committee of the Corrosion Committee would be to settle the matter once and for all.

With the second main conclusion reached by Mr. Richards, everyone would probably be in entire agreement. The author very clearly stated on p. 161 that, other things being equal, the heaviest practicable coating of zinc was to be aimed at. Personally, he thought that the whole result of recent work on the protection of iron and steel against corrosion had been to show that it was false economy to be unduly parsimonious with protective coatings. That statement certainly applied in the case of painting, where, as had been demonstrated time after time, it was foolish to economise on the expenses incidental to surface preparation, and it was a waste of money to buy excessively cheap paints. In the same way, he thought it would be obvious to everybody that the same conditions held true for galvanised coatings and that, whenever practicable, a reasonably thick coating of zinc should be applied, suitably designed to withstand the conditions of service of the job in hand.

Indeed, the chief value of work such as that described by Mr. Richards in the present paper was that, by obtaining clear and precise data as to the rates at which zinc and other metallic materials might be expected to corrode in different types of atmosphere, it became possible to use the materials to the best economic advantage and to choose the most economical protective coating for any given set of conditions. There would, for example, be no point in putting a very thick zinc coating on a wire that was to be used at Khartoum, for the simple reason that the steel would not corrode appreciably there even if it had no zinc on it at all; nor was it necessary to galvanise a wire so heavily for use in a pure country atmosphere as for use in an industrial one. Thus, as a result of careful tests such as those of the author, the time might come when it would be possible to produce various grades of galvanised products intended for use in different localities, and in that way research of this type would enable definite progress to be made, not only scientifically but also in regard to commercial applications.

Mr. L. KENWORTHY (London) said that there were two points which he would like to raise in connection with the excellent paper by Mr. Richards. In the first place, he thought perhaps a little more emphasis might be laid on the effect of the diameter of the wire in resisting atmospheric corrosion. For example, referring to Table XIV., and averaging the six materials which were exposed in both gauges (*i.e.*, Nos. 11, 12, 13, 16, 17 and 18), it was found that the average effective life of coatings on the 8-gauge wires was 2·87 years and on the 14-gauge 2·41 years. Taking the reciprocals of these figures, it would be found that the relative rate of attack on the 14-gauge wire was 19% greater than that on the 8-gauge wire. It would appear, therefore, that any specification for galvanised wire intended for outdoor exposure should take into consideration the gauge of the wire.

With further reference to the effect of diameter, it was very interesting to compare the difference in the corrosion rates between the two gauges with the difference in their rates of attack in the copper sulphate dip test. Taking the same six wires in Table I., the average rate of attack, as shown in column *M*, was 0·20 oz. per min. for the 8-gauge wires and 0·24 oz. per min. for the 14-gauge. The average attack on the thinner wires was thus 20% greater, as compared with a difference of 19% in the atmospheric attack. Thus, although diameter was only one of many complicating factors in the Preece test, the effect of which in the normal way was swamped by other considerations, in this case, where the effect of diameter might to a large extent be isolated by a comparison which eliminated the other variables, the agreement between the ratio of attack in copper sulphate and that on atmospheric exposure was indeed quite remarkable. It seemed probable, therefore, that where the effect of diameter alone could be determined, the rate of attack of a galvanised coating in copper sulphate would afford a useful accelerated test for determining the probable lives of coatings on wires of gauges other than those included in the present field tests.

His second point related to the nature of the atmosphere at Shepherd's Bush. Reference to Table VII. showed that, although it was classified as an urban atmosphere, it corroded zinc at a rate only exceeded by St. Helens and Widnes, whilst the ratio of the relative rates of attack of zinc to iron was the smallest of any of the exposure sites investigated. He would like to know if Mr. Richards could give any explanation of this.

Mr. S. C. BRITTON (Derby) said that although the Preece test had been assailed many times before, the assault had never, he thought, been so thorough or accompanied by such devastating results as this almost accidental blow delivered by Mr. Richards. He hoped that as far as specification testing was concerned the effect would be mortal to the method. The results showed that even the adoption of a correcting factor for each process of zinc coating, as

had been suggested by Groesbeck and Walkup, in America, could not make the Preece test give reasonable satisfaction. In fact, from Mr. Richard's experiments it seemed that a correcting factor for every manufacturer would be necessary. Even the tendency found by the author for the products of one manufacturer to give comparable results in the Preece test would probably hold only so far as one type of coating was concerned, because a wiped wire and a fully galvanised wire did not show the same rate of attack by copper sulphate, even when produced by the same factory.

The similarity in the corrosion rate found by the author for various types of coating also went to indicate that the various other methods of test based on the speed of attack of the coating by acids would not satisfactorily predict the resistance to atmospheric corrosion. He believed that most galvanised wire was in service in conditions of purely atmospheric exposure, and it seemed, therefore, that as a specification test it was desirable to use one of the two available stripping methods to determine the thickness of the coating.

Personally, his experience with the B.N.F. test suggested that it was more reliable than the determination of the total weight of coating, but the superiority was so small that he thought the choice between the two tests must depend on convenience in application. In that connection, it might be noted that the B.N.F. test included a proposal for testing a wrapped and restraightened wire to indicate brittleness, so that both the weight of coating and the brittleness were tested with the same apparatus and solutions. If a chemical stripping test were adopted, and the brittleness test remained the copper sulphate dipping test, two quite different sorts of test would have to be made. A brittleness test was certainly desirable, and he would suggest that Mr. Richards' conclusion that a heavy coat which cracked was superior to a lighter one which did not crack was limited to wire for certain classes of service. The author's conclusion would certainly be justified by purely corrosion tests, but for conditions in which wire was subjected to bending stresses a ductile coating was desirable. There was some evidence from laboratory work (for example, Shelton [1] and the discussion on his paper by Fuller) that fatigue flaws might originate at cracks in a zinc coating. In a service failure that he had met with, a galvanised wire failed by fatigue at a loop, the coating of which had been cracked. It seemed likely, in view of the previous good performance of wires on that service and the absence of any other obvious defect, that the cracks had had a notch effect.

The extent of the protection given by the remaining zinc coating to the steel exposed at gaps was noteworthy, but that did not surprise him, for Dr. Evans and himself had found that even a zinc pigmented paint seemed to confer some protection on bare steel

[1] *Proceedings of the American Society for Testing Materials*, 1931, vol. 31, Part 2, p. 210.

gaps. It seemed from the fact that in laboratory tests the rate of loss of weight of the wire was distinctly decreased by the presence of bare bands of iron that the protection might not be due to anodic "sacrifice" of zinc but perhaps to an inhibitive action of the zinc salts, produced by solution of the coating, on the corrosion of steel.

With regard to the relative rates of corrosion of zinc and steels in the atmosphere, probably not only the extent of the sulphur dioxide pollution was concerned but also the duration and number of drying-off periods. Thus in the Dove Holes tunnel, where the SO_2 concentration did not normally reach more than half that in the Dollis Hill spray chambers, but where the drying-off periods were short and infrequent, Dr. Hudson found the rates of corrosion of zinc and ingot iron to be quite close together, as had been stated in the Fourth Report of the Corrosion Committee.[1]

It was evident that, even accepting the figure of 25% loss in strength used by Mr. Richards as the scrapping limit, a small improvement in the corrosion resistance of the steel base by, for example, copper additions would extend the total life of galvanised wire very little. In practice the final loss of strength of galvanised wire in many forms of service was less than 25%. Those responsible for its maintenance in a safe condition could not judge how much strength a rusty wire had lost and therefore replaced the wire at the first appearance of rust. It did, however, seem worth while to pursue the possibility of replacing galvanised wire by a more resistant material in some localities. The initial cost of austenitic stainless steel wire made it a very doubtful investment, using calculations with Mr. Richards' figures for the probable life and for erection and interest costs. Had no other alternative been considered? Would not the extensive Post Office experience with copper telephone wires justify an experiment with a high-tensile copper alloy for stay wires? On the London, Midland and Scottish Railway, experiments with copper alloy wire in some atmospheres which were rather corrosive to galvanised coatings were giving promising results.

CORRESPONDENCE.

Mr. T. Henry Turner (Doncaster) wrote that railway engineers must be in regular co-operation with the engineers of the Post Office, so he had found much of interest in Mr. Richards' paper and had endeavoured to compare the figures which he gave with railway practice. His Company's solid fencing wires lasted two or three or even more times as long in the country as in the London district. Their stay wires had lives of five to fifteen years, according to the district.

The very short lives of stay wires in industrial districts deserved

[1] *Iron and Steel Institute, Special Report No.* 13, p. 46.

attention. Stay wires on railway telegraph poles in industrial districts were frequently very badly rusted. They were not painted. On the other hand, similar stay wires supporting power lines, maintained by the railway electrical engineers, were regularly painted and had an almost indefinite life.

This observation of difference in practice reminded him that when Mr. Kenworthy gave his paper to the Institute of Metals last autumn on "The Method of Testing Zinc Coatings," he (Mr. Turner) had said that he thought engineers should not be satisfied with galvanised coatings and that they should supplement the protective value of the zinc with a coating of paint, varnish, or other protective material.

The author's figures showed clearly that small percentages of iron in zinc coatings were of little importance where the coated wires were to have a short life in industrial atmospheres. For such purposes, the hot-galvanised or electroplated wires could be used indiscriminately. Zinc gave a relatively better protection under rural conditions, hence one should assure a continuous, non-cracking coat of zinc for wires exposed to rural or marine conditions. Electroplated zinc wires might here be preferred, so long as they met the same specification as regards ounces of zinc per square foot. A minimum of about an ounce of zinc per square foot seemed necessary.

He was not in agreement with the author's condemnation of the Preece test, on the basis of relatively small samples which had not swung in the wind. He agreed that the partial stripping tests indicated that zinc exerted a marked protection of bare areas near to it. Nevertheless, there could be no doubt that a uniform thickness of zinc coating was to be preferred to a lumpy irregular deposit, and the Preece test differentiated between two wires which had the same weight of zinc per square foot, one of which was covered by a uniformly thick coating and the other by a lumpy irregular coating that would fail at some spots sooner than others. He still believed such a wire would break in service sooner than one covered with a uniform deposit of zinc.

Table VII., p. 144, showed that the value of galvanising, although considerable, became relatively less as the conditions became more severe. Railway tunnel atmospheres were worse than those of most industrial districts and zinc coatings were very short-lived in tunnels.

Fig. 4 was very instructive, even idealised as it had been and based on steady tensile stress. The loss in strength would presumably be more marked if impact loading had been employed, and under atmospheric storm conditions impact loading might well be received by the stay wires. From his point of view, Fig. 4 indicated that if galvanised stay wires were painted not later than a year after their erection, they should last as long as painting was maintained, but if they were not painted, their zinc coating would very soon be valueless.

Solid wires were cheaper and lasted longer than stranded cables. They might be awkward to bend, but he saw no insuperable difficulty

in the use of solid oval or flat straps of annealed mild steel in place of the present cables. The pitting in a solid strap would be less than that in a bunch of small wires. He noticed that the composition of the bare wires given in Table IV. showed no appreciable copper content. Was this by design, as, from the corrosion point of view, ½% of copper should have been beneficial?

The figures given by the author regarding austenitic stainless steel were most interesting, and he would like to ask whether he had considered the possibility of using single oval wires, straps or other sections of austenitic stainless steel in the annealed unpolished condition (but pickled to remove the oxide). The thicker single section of the corrosion-resisting steel should give a better life than the thinner multiple sections of galvanised stranded wire, especially bearing in mind that the zinc would be no longer in existence after a year or two in industrial areas.

Mr. Turner submitted for the author's examination a sample of 7½-gauge telegraph line wire, which was still round where the binding wire has protected it at the insulator, but had corroded away to an irregular knife-blade section 3 in. from the insulator, owing to the lateral swinging of the wire having cracked off successive coats of rust.

AUTHOR'S REPLY.

Mr. RICHARDS, in reply, wrote that he wished to thank Dr. Evans and the other speakers for the kind way in which they had received the paper.

He would try to reply to the points raised in order. Dr. Evans referred to the sacrificial protection afforded by zinc at places where the coating was broken. It was only fair to add that the example that he quoted from the paper referred to a straight wire which should not originally have had any discontinuities in the coat. With an electronegative coating the fall in strength would have been pronounced before the major part of the coating had been removed.

In all cases of tests on new finishes he agreed that tests on specimens having scratch marks or other discontinuities were essential.

Commander Rylands raised the interesting point of the effect of small amounts of impurities on the behaviour of the zinc coatings. He (the author) had felt that this could not be included in the present work, which was concerned only with commercial grades of wire, as there was a great risk of becoming lost in a maze of incomplete information. Such problems could probably best be handled by starting from pure materials and dealing with the impurities one by one.

Referring to the ductility of coatings, most of the wires at

present being supplied would readily pass the "four-times mandrel test" which was now standard in Great Britain, and no more stringent test appeared necessary; in fact, on his own showing a wire which would pass the four-times mandrel test would probably withstand a much more stringent one. In the case of stay wires good ductility was required so that the coating should not strip at the "make-off." In connection with this he had made the interesting observation that if a wire was coiled in a close helix, *i.e.*, with the turns touching one another, the rate of removal of zinc was much slower than with an open helix or a straight wire.

He was glad to hear from Dr. Hudson of the close agreement between their results. He had been carefully through most of the work published by the Corrosion Committee and in many cases the agreement was striking.

The question of the effect of the purity of the zinc, particularly in thin coatings, was one which he had not studied. Mr. Kenworthy drew attention to the apparent correspondence between the relative rates of corrosion of the Nos. 8 and 14 S.W.G. wire and their rates of attack by copper sulphate solution. It was a point which he had not noticed and to which he would give further attention. Mr. Kenworthy also pointed out that any specification for galvanised wire for outdoor use should take into consideration the diameter of the wire. In principle, he (the author) agreed, but the inference that he drew from the remark was that the thinner the wire, the thicker should be the zinc, and he felt certain that the galvanisers, with the best will in the world, would not be able to meet such a requirement.

The atmosphere at Shepherd's Bush had provided a puzzle. Judged on results, one should regard it as one of the worst industrial atmospheres, but the plain fact was that it was largely a residential district and for this reason alone the results had been classified with those of urban areas. Shepherd's Bush was a rather smoky area, and he believed that the atmospheric pollution records bore this out.

The use of high-tensile copper-alloy wires was suggested by Mr. Britton as an alternative to galvanised iron. The author had no experience of the use of these alloys, but he knew that in many cases it had been found necessary to protect bronze and cadmium-copper line wires from atmospheric corrosion by means of an impregnated fabric. The indications were that in many districts bronze and galvanised iron had very similar lives, the bronze in most cases being slightly the better.

Mr. Turner had introduced many important points in his communication, and the author agreed that where practicable galvanised fittings should be painted before the zinc had been corroded away. In this way a much greater life should be obtained, particularly in industrial districts. He agreed also that a uniform coating of zinc would probably outlast a lumpy one of the same

thickness, but would point out that, although he considered that the Preece test should give way to the stripping test, he still thought that the ductility test, which included a shorter-time copper sulphate dip, should be retained. In this way the best possible material should be obtained.

The author thought Mr. Turner was right in suggesting that the loss in strength of rusted wires would be greater if shock loading were employed.

He had thought very seriously about the use of solid straps as alternatives to stranded wires. In theory they should be an improvement as was suggested, but he could not avoid a feeling of reluctance to employ them for stays and similar work, now normally done by stranded cable. It might be innate conservatism or it may be just a feeling that solid straps could never be tensioned to form straight stays, but in spite of the soundness of the idea, he did not like it!

He had examined with great interest the telegraph wire which Mr. Turner submitted. The way in which the wire had thinned down just away from the insulator was truly remarkable.

With regard to the copper content of the wires, no stipulations were made when purchasing supplies. They were bought to comply with B.S.S. 183. It was found during tests that at least one supply of wire had an appreciable amount of copper in it. This was mentioned in the text of the paper just below Fig. 5.

COMPARISON OF THE TENSILE DEFORMATION CHARACTERISTICS OF ALLOYS AT ELEVATED TEMPERATURES.*

By Professor CHARLES R. AUSTIN and H. D. NICKOL (Pennsylvania).

(Figs. 23 to 36 = Plates VIII. to XXI.)

THE purpose of the present investigation was to obtain a comprehensive survey of the high-temperature strength above a red heat of some of the alloys which may be considered as essentially high-temperature materials, and to present a study of the microstructural characteristics of the alloys.

Part I. of the paper deals with a description of a new type of testing equipment, and with a comparative study of the deformation characteristics of seventeen alloys. In Part II. are discussed the effects of time, temperature and stress on the microstructural changes occurring in the alloys, followed by a general discussion of the work, correlating the metallographic features with the data described in Part I.

PART I.—Details of New Creep Apparatus with Data on Deformation Characteristics at 600° to 1000° C.

Abstract.

This part of the paper presents details of a new type of equipment for the comparative study of stress/deformation/time relationships of alloys at elevated temperatures. The behaviour of seventeen alloys at 600°, 700°, and 800° C. under stresses ranging from 2000 to 8000 lb. per sq. in. is indicated by tabulated data and by deformation-time curves arranged to illustrate the three classes of alloys studied :

(1) Austenitic stainless 18/8 steels.
(2) Ferritic chromium-iron alloys.
(3) Konel-type alloys—*K42B* and modifications.

A few data are also included relating to resistance to deformation at 1000° C., and at 950° C. in a hydrogen atmosphere.

Consideration has been devoted to the reproducibility of the test data, to negative dilatation of the alloys, to a comparison of results from single and multiple loading, and finally to the distribution of the data from tests exhibiting low and high rates of deformation.

Since the time when Dickenson,[1] in 1922, emphasised the profound importance of the rate of loading on the values obtained to

* Communication from the Department of Metallurgy, Pennsylvania State College, received September 7, 1937. Parts of this investigation were submitted by Mr. Norris as partial fulfilment of the requirements for the M.Sc. degree.

indicate the high-temperature strength of steels, a vast amount of data on the properties of alloys at elevated temperatures has been added to the technical literature. Much has been written on the relative importance of so-called long- and short-time creep tests, but no unanimity of opinion seems to have resulted.

The chief endeavour of investigators has been directed towards an increase in the sensitivity of the test, as regards both temperature uniformity and accuracy of temperature control, and also an increase in the accuracy of the measurement of the elongation during the progress of the creep test. Industrial demands, where minute amounts of creep elongation are of the utmost importance, have constituted a strong urge in this direction. Thus, in steam-turbine design, Allen [2] has quoted the figure of 0·01% per year as being a satisfactory creep rate for high-temperature turbine parts. This is equivalent to approximately 0·00000001 in. per in. per hr. The need for maximum accuracy in recording change-of-length measurements is therefore at once apparent, but whether our metallurgical alloys warrant the use of such data for design purposes is another matter.[3]

Data pertinent to this observation have recently been presented by Jenkins, Tapsell, Mellor and Johnson [4] before the World Power Conference in Great Britain. These authors discussed the comparative creep properties of wrought carbon steels at 450° C., and showed, for a constant stress of 8 tons per sq. in., rates of creep at the end of 20 days varying from $0{\cdot}3 \times 10^{-6}$ to 107×10^{-6} in. per in. per hr. for similar carbon steels containing about 0·15% of carbon. The steels were tested after air-cooling from 950° C., and no satisfactory explanation for the wide divergence in creep behaviour was indicated, despite the fact that the above recorded data represent a ratio of 1 : 350. Even omitting data for the one steel which the authors called "abnormal," the remaining five steels had creep values ranging from $0{\cdot}3 \times 10^{-6}$ to $1{\cdot}3 \times 10^{-6}$ in. per in. per hr. The latter value represents a 300% increase over the former.

Among the seven 0·4% carbon steels which were tested, a much closer correlation was obtained, but even with this series of steels of "similar" chemical composition creep rates resulting from a stress of 8 tons per sq. in. for 20 days varied from $0{\cdot}4 \times 10^{-6}$ to $2{\cdot}1 \times 10^{-6}$ in. per in. per hr.

Thus it would appear that there is really a greater need for studies that might be expected to furnish information on the factors which control what may be termed the inherent creep properties of alloys, rather than for extending the number of decimal points to which the creep rate can be calculated for any one given specimen of a metallic alloy. Furthermore, this conception is also important in discussing what may be considered an adequate length of time for a creep test, since again, omitting consideration of short-time tests, one is usually concerned with the effect of time on some fractional

correction of a value for the creep rate deemed to have been obtained from too short a test time.

The above comments are not to be construed as commending short-time creep tests, but rather as questioning the significance of an accurately evaluated creep rate after several thousand hours of test, for a given alloy composition which is to be used for a commercial application.

More recently, investigators [5] have been directing attention to the effect of time on microstructural changes in alloys, and engineers are beginning to appreciate that the alloy at the end of several hundred or thousand hours of test may be structurally quite different from what it was at the start of the test. Naturally these comments are also equally applicable to service conditions. Corrosion or erosion effects in service may still further militate against the significance of the experimental creep data.

Thus it is evident that more information is required on the degree of stability of alloys at elevated temperatures and on the factors which modify the rate of change from the unstable condition towards a more stable structural state. It will readily be recognised that even the approximately stable state in alloy materials is of little use in the vast majority of commercial applications and that for service at elevated temperatures it is necessary to select engineering materials which are likely to change, during service life, only within certain ill-defined limits.

The Alloys Investigated.

The alloys discussed are conveniently classified into three distinct groups:

(1) The 18/8 stainless steels which are normally austenitic.

(2) The low-carbon chromium irons, either free from nickel or containing that element in such limited quantities that the alloys are ferritic.

(3) The konel-type of alloys developed at the Westinghouse Electric and Manufacturing Company, which are essentially nickel, cobalt, ferro-titanium alloys modified by the addition of chromium or tungsten. A comprehensive survey of certain other high-temperature properties of these alloys was recently published by the senior author.[6]

Either the chemical analyses or the nominal compositions of all the alloys discussed in the paper are given in Table I. It may be noted that the analyses of the stainless steels are fairly similar with the exception of the addition of $\frac{1}{4}\%$ of selenium to alloy 303*C*. In the chromium irons there are two so-called stainless irons with 12% of chromium where the chief variation is in the carbon content. It should also be noted that the 24% chromium iron contains both nickel and molybdenum.

TABLE I.—*Composition of Alloys Tested.*

Alloy Designation.	Chemical Analyses of 18/8 Type Alloys.							
	C. %.	Cr. %.	Ni. %.	Mn. %.	Si. %.	S. %.	P. %.	Se. %.
LE . .	0·07	18·16	8·09	0·36	0·20	...	...	...
AMK . .	0·10	18·47	8·63	0·43	0·32	0·018	0·021	...
18/8 . .	0·066	18·29	9·22	0·55	0·33	...	...	...
302*C*. Melt *A*.	0·07	18·25	8·94	0·44	0·47	...	...	...
302*C*. Melt *B*.	0·07	18·55	8·92	0·34	0·65	0·009	0·012	...
303*C*. Melt *A*.	0·09	18·53	9·04	0·81	0·62	...	...	0·248
303*C*. Melt *B*.	0·09	18·33	9·04	0·78	0·57	0·013	0·131	0·252
Nichrome .	...	(20)	(80)	...	...	...	...	...

	Chemical Analyses of Low-Nickel Type Alloys.							
	C. %.	Cr. %.	Ni. %.	Mn. %.	Si. %.	S. %.	P. %.	Mo. %.
Silchrome .	0·42	8·48	...	...	2·87	...	...	...
Stainless iron .	0·06	12·60	0·43	0·37	0·24	0·006	0·017	...
A33K . .	0·12	12·97	0·416	0·49	0·240	0·017	0·020	...
A66K . .	0·11	18·08	0·287	0·42	0·254	0·019	0·017	...
329*C* . .	0·09	24·40	3·41	...	...	...	...	1·60

	Nominal Composition of Konel Type Alloys.						
	Ni. %.	Co. %.	Fe. %.	Ti. %.	Cr. %.	W. %.	Comments.
Konel . .	73	17	7·5	2·5	...	...	Konel
2948 . .	46	25	7·5	2·5	19	...	*K42B*
3107 . .	23	47	7·5	2·5	20	...	*K42B* with Ni/CO reversed
2907 . .	46	25	7·5	2·5	...	19	W for Cr in *K42B*
2870 . .	48	25	7	...	20	...	Ti-free *K42B*
3124 . .	...	85	11·25	3·75	...	...	85 Co, 15 Fe_3Ti

The konel-type alloys are of particular interest by virtue of the remarkable tensile properties of alloy *K42B* [7] and of alloy 3123 [6] (80% cobalt and 20% ferro-titanium) found on testing at 600° C. The alloys of this type included in Table I. were selected principally to illustrate the effect of interchanging the nickel and cobalt in alloy *K42B*, of substituting tungsten for chromium in the same alloy, and of omitting additions of titanium.

All but three of the alloys tested were received in the form of $\frac{3}{16}$-in. dia. bar stock. Alloys *AMK*, *A33K* and *A66K* were supplied as $\frac{5}{16}$-in. dia. rod.

No detailed information was available on the fabrication of all the alloys, but the limited data submitted are as follows:

Alloy LE.—A 7-in. square ingot cogged to 3½-in. square, recogged to 1½-in. square and finished to ¼-in. dia., then cold-drawn to 0·193 in. dia., annealed at 1120° C. and centreless-ground to $\frac{3}{16}$ in. round.

Alloys 302C *and* 303C.—302*C* made in arc furnace and 303*C* in induction furnace. Bars rolled and brought to final size ($\frac{3}{16}$ in. round) by cold-drawing. Melts *A* of both materials were furnished in cold-drawn, annealed and cleansed condition. Melts *B* were cold-drawn, annealed and ground.

Description of the Apparatus.

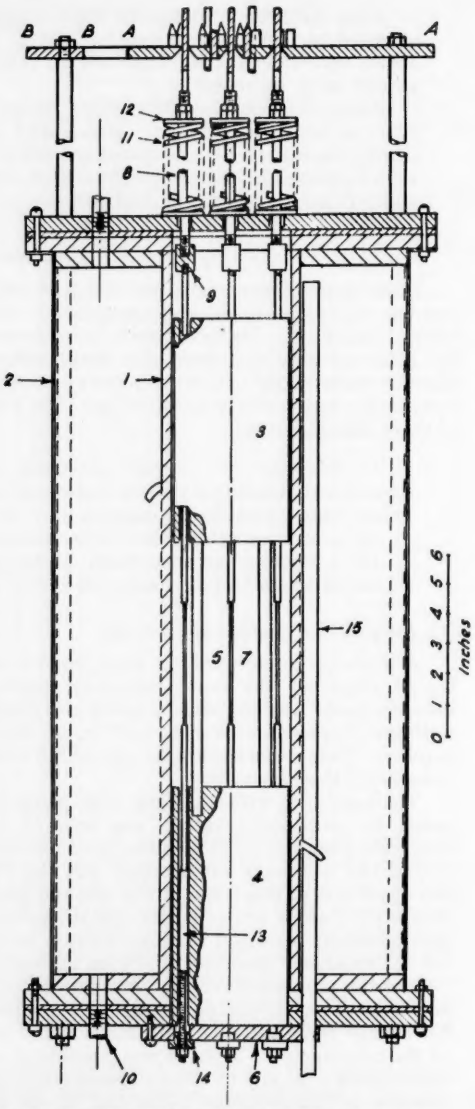
A new type of apparatus was designed and constructed for the purpose of evaluating the high-temperature deformation characteristics of the alloys. Its chief merits lie in the simplicity of operation, the economy resulting from the simultaneous testing of several alloys concomitantly in a single piece of equipment, and the strictly comparable test conditions obtaining. The test equipment consists of three essential parts :

(1) The furnace proper, provided with means for independently loading six test samples and with suitable reference points from which length changes may be measured,
(2) a microswitch method of temperature control, and
(3) a micrometer wired into a grid glow-tube circuit, by means of which length changes of 0·0001 in. may be observed.

(1) *Furnace and Method of Loading.*

A sectional drawing of the equipment is shown in Fig. 1; the legend describes the more important parts of the furnace. A uniform main winding with a lower auxiliary winding provides a uniform temperature over 4½ to 5 in. at the centre section of the furnace. Below this section the rate of fall in temperature was much more rapid than above it.

The specimen, with a uniform 4-in. gauge length of ⅛-in. dia. prepared by centreless-grinding, was screwed into one of the lower extension members (13) and introduced into the furnace, and the top end of the specimen was screwed into the upper bushing (9). In the upper end of this bushing was screwed permanently an extension member (8) which projected beyond the reference plate (*A*). Three symmetrically arranged seatings, located so as to surround each of the six extension members (8), were inserted in the reference plate (*A*) for the purpose of seating the micrometer. Each set of seatings consisted of two conical points and a flat contact area, which matched the hollow cone, V-notch and conical point, respectively, in the feet of the micrometer. Thus, it was possible at any time to replace the micrometer over any of the six specimens at the same fixed position relative to the reference plate and to the extension member (8).



1. Alundum tube.
2. Furnace container.
3 and 4. Insulating brick.
5. Porcelain supports for upper refractory.
6. Cover plate to hold tension in test specimens.
7. Gauge section of test specimen.
8. Upper extension rods.
9. Bushing connecting specimen with (8).
11. Calibrated spring.
12. Upper spring bushing.
13. Lower extension rods.
14. Bushing for (13).
15. Alloy tube for temperature control. (*See* Fig. 3.)

FIG. 1.—Section through Deformation Test Furnace showing Details of Construction.

This reference plate was fixed with respect to the lower stationary end of the specimens by three invar rods, outside the furnace, which maintained it in the same position regardless of room-temperature fluctuations. Accordingly, any length changes in the specimens could be observed up to the accuracy of the micrometer.

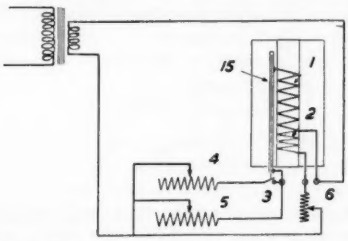
A predetermined load was applied to each test specimen by means of a calibrated spring (11). From time to time a check on the calibration was obtained by first turning down the nut situated immediately above the spring bushing (12), through the number of turns required to compress the spring by an amount indicated by calibration, and then dead-loading the test bar underneath the furnace. Correct compression was indicated when the spring was just free from any compression from the nut on the lower extension member below the bushing (14).

With very low creep rates the error due to loss of compression caused by a minute elongation of the test bars was negligible. With marked elongation the compression was periodically adjusted by compressing the spring by an amount equal to the creep extension of the test sample.

A photograph of the complete equipment is shown in Fig. 23.

(2) *Temperature Control.*

Satisfactory temperature control of the furnace was obtained by the use of a microswitch operated by a silica rod carried inside a closed stainless-steel tube. A simplified wiring diagram is shown

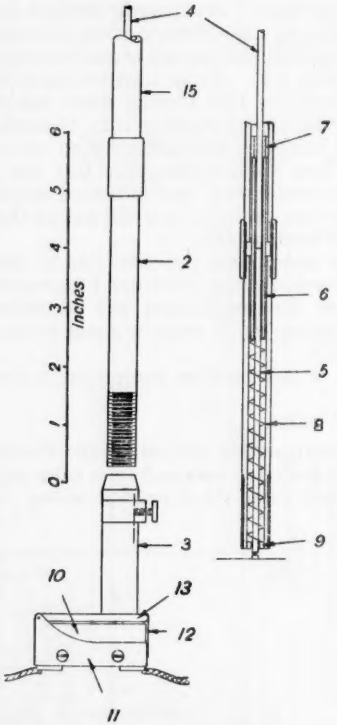


1. Main heating coil.
2. Auxiliary heating coil.
3. Microswitch.
15. Control tube in series with (1).
4 and 5. Rheostats for voltage adjustment for maximum and minimum current.
6. Rheostat to adjust current in auxiliary.

FIG. 2.—Simplified Wiring Diagram for Furnace.

in Fig. 2, where it may be noted that the alloy tube (15) was placed close to the main furnace winding as well as being made part of the electrical circuit of the main winding. For these reasons the

temperature fluctuation in the control tube was rapid, and a maximum temperature variation of 2° C. was maintained in the furnace.



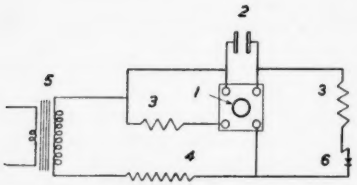
2. Coupling between control tube (15) and micrometer (3).
3. Micrometer adjustment for microswitch (10).
4. Silica rod operating button of micrometer switch through steel rod (5).
6. Metal sleeve.
7 and 9. Centering bushings.
8. Helical spring spacer.
10. Burgess micrometer switch.
11 and 12. Supports for the microswitch.
13. Metal plate welded to micrometer barrel (3).

FIG. 3.—Temperature Control Unit.

The details of construction of the control unit are indicated in Fig. 3. With the legend it is self-explanatory.

(3) *Micrometer Indicator.*

Clearly the accuracy of the micrometer readings, which governed the measurements of length changes of the test bars, depended on the sensitivity with which contact could be made between the micrometer and the tip of the extension members at the reference plate. Unsatisfactory results were obtained by mechanically finding the exact position of such contact, so a simple " grid glow-tube " was employed. Details of the circuit are given in Fig. 4.



1. Grid glow-tube.
2. Condenser, 0·00005 microfarad.
3. Resistance, 10 megohms.
4. Resistance 25,000 ohms.
5. 110–440 V. transformer.
6. Micrometer contact.

FIG. 4.—Circuit of Grid Glow-Tube Used as an Indicator for the Micrometer.

A grid glow-tube [8] is an extremely sensitive device which emits a glow when electrical contact is made in a suitably arranged electrical circuit. The use of this contact indicating method permitted length changes of 0·0001 in. to be observed with accuracy.

On account of the small temperature cycle resulting from the method of temperature control, the periodic readings made in order to follow the length changes were taken as the furnace cooled through the mean test temperature. A change of 1° C. in the furnace could be detected by the micrometer on account of the dilatation of the test bars.

Details of Test Procedure.

The standard test specimen consisted of a $\frac{3}{16}$-in. dia. rod, 20 in. long, threaded at both ends, with a centreless-ground 4-in. gauge length, 0·125 $\pm$ 0·0005 in. dia., at a distance of 5 to 9 in. from one (the lower) end of the test bar. Specimens of *AMK*, *A33K* and *A66K* were $\frac{5}{16}$-in. dia. rods with the 4-in., 0·125-in. dia. gauge length.

All specimens were annealed for 15 min. at 950° C. in hydrogen and air-cooled. On account of the small cross-section, this treatment constituted a rapid method of cooling. The temperature selected was arbitrary and uniform, since no information on the optimum temperature for heat treatment was available. The stainless 18/8 steels were treated similarly, since they were to be tested at 600° C. and above.

After normalising, the six test samples, held in the lower extension members, were inserted into the hot-deformation furnace and screwed into the upper extension members. As soon as the complete unit

had attained temperature equilibrium, each specimen was adjusted so that the springs held the rod tightly in position but did not subject it to any tensile stress.

Micrometer records under this condition provided the reading for zero load. Having calculated the total number of turns of the nut, above the spring, to give the spring a compression equivalent to a desired stress in pounds per square inch, the test rods were progressively stressed, and micrometer readings were taken at the appropriate part of the temperature cycle so that a stress-strain curve might be plotted for all tests.

When all six specimens were fully loaded the plastic deformation part of the test was allowed to proceed for several days or weeks, several readings per day for each alloy being recorded by means of the micrometer.

Normally one test rod of an alloy was used for the complete series of tests at each temperature, and the stresses used were 2000, 4000, 6000 and 8000 lb. per sq. in. in the order named. In the first few tests conducted by K. H. Mairs, who was associated with the experimental work in the early stages, specimens were removed from the furnace at the completion of the test under 2000 lb. per sq. in. and renormalised from 950° C. This procedure was repeated at the conclusion of the 4000- and 6000-lb. per sq. in. load. In later tests, after appropriate time intervals, the loads were progressively increased without subjecting the test bar to any intermediate heat treatment. Usually the test period at constant stress ranged from 250 to 350 hr.

Accordingly, when the stress was increased to 4000 lb. per sq. in. the specimen had already been at temperature under a stress of 2000 lb. per sq. in. for perhaps 300 hr. Before increasing the load to 6000 lb. per sq. in. the test bar had been at temperature for 600–750 hr., and thus before the final load of 8000 lb. per sq. in. the previous history of a specimen tested at 700° C. was approximately as follows:

(1) Annealed for 15 min. at 950° C. and air-cooled.
(2) 300 hr. at 700° C. under 2000 lb. per sq. in. stress.
(3) 300 hr. at 700° C. under 4000 lb. per sq. in. stress.
(4) 300 hr. at 700° C. under 6000 lb. per sq. in. stress.

When the four loads had thus been applied the total test period approximated to 1200–1500 hr. of test. The diagrams have been clearly marked to indicate wherever the early procedure of normalising between load increments was employed.

Results of Deformation Tests.

In Tables II., III. and IV. may be found a condensed summary of the deformation data at 600°, 700° and 800° C. under 2000, 4000, 6000 and 8000 lb. per sq. in. for the stainless steels and nichrome, for the low-nickel chromium irons and silchrome, and for the konel-type alloys. From these Tables the hours of test, the percentage creep rate per 1000 hr. after 250 hr. under the recorded

stress, and the total elongation for the same period may be noted. The general appearance of the strain-time curves is illustrated in Figs. 5 to 13.

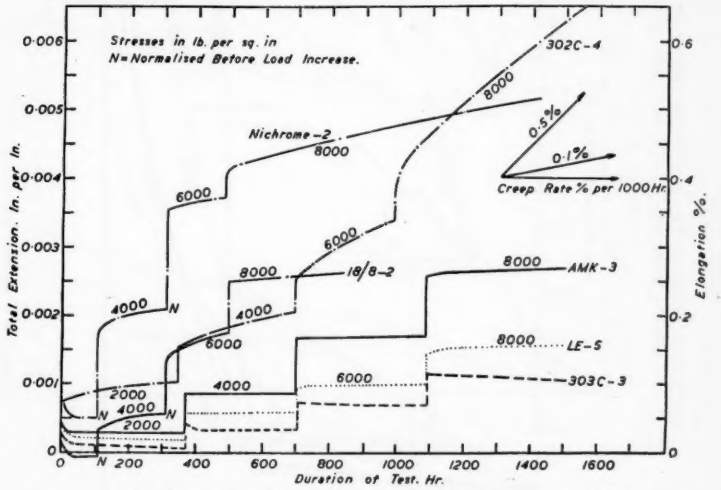


FIG. 5.—Creep Characteristics of 18/8 Type Stainless Steels at 600° C. and 2000, 4000, 6000 and 8000 lb. per sq. in.

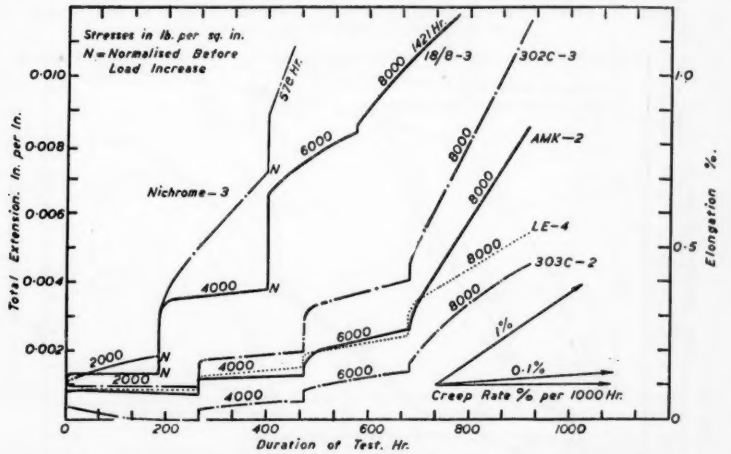


FIG. 6.—Creep Characteristics of 18/8 Type Stainless Steels at 700° C. and 2000, 4000, 6000 and 8000 lb. per sq. in.

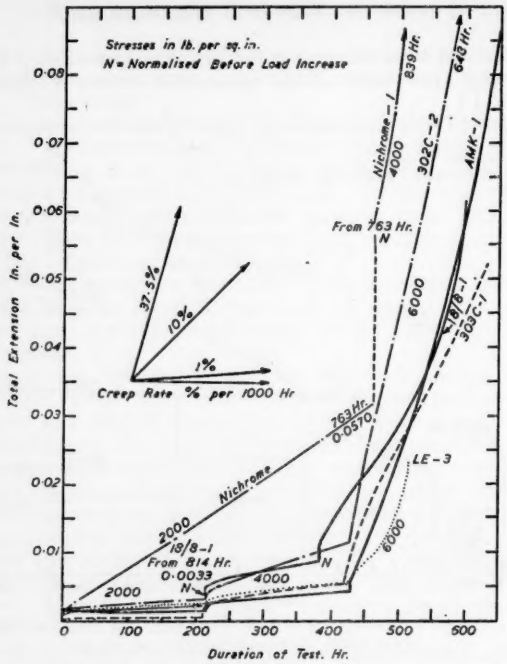


FIG. 7.—Creep Characteristics of 18/8 Type Stainless Steels at 800° C. and 2000, 4000 and 6000 lb. per sq. in.

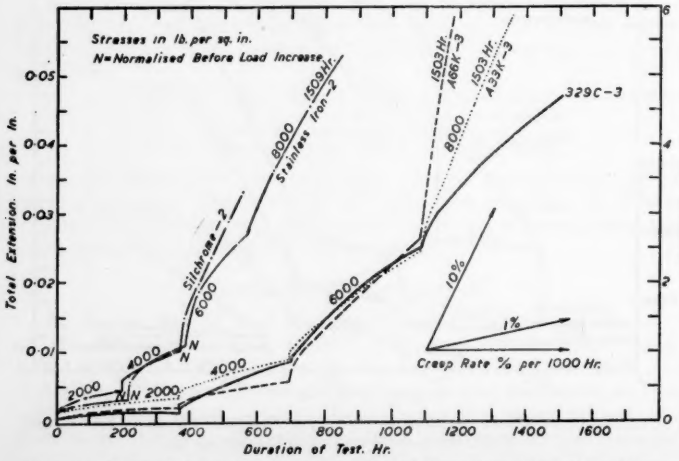


FIG. 8.—Creep Characteristics of Low-Nickel Type Iron-Chromium Alloys at 600° C. and 2000, 4000, 6000 and 8000 lb. per sq. in.

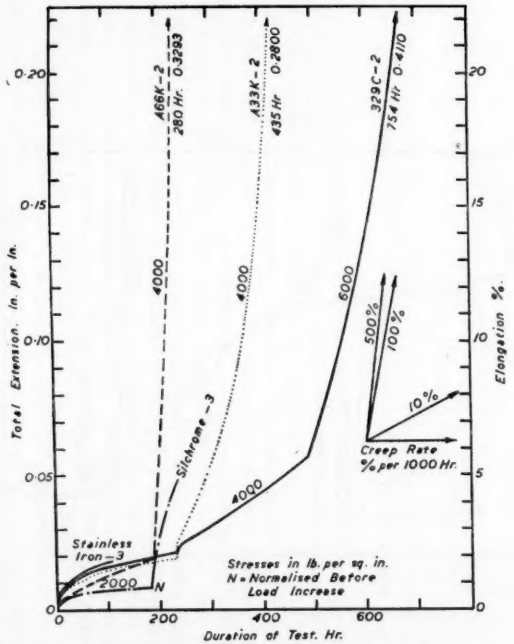


FIG. 9.—Creep Characteristics of Low-Nickel Type Iron-Chromium Alloys at 700° C. and 2000, 4000 and 6000 lb. per sq. in.

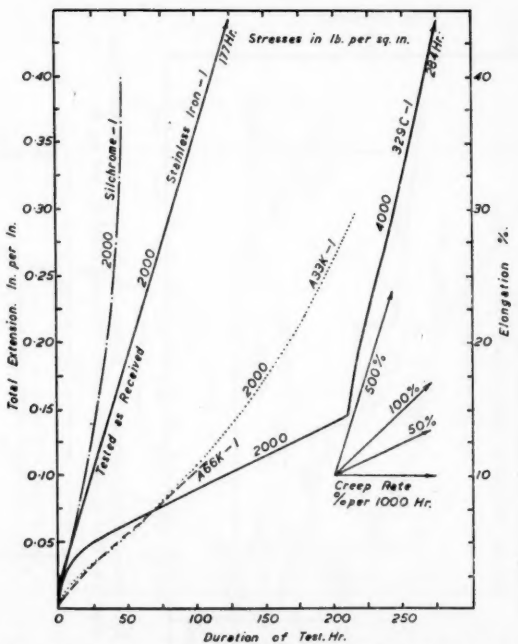


FIG. 10.—Creep Characteristics of Low-Nickel Type Iron-Chromium Alloys at 800° C. and 2000 and 4000 lb. per sq. in.

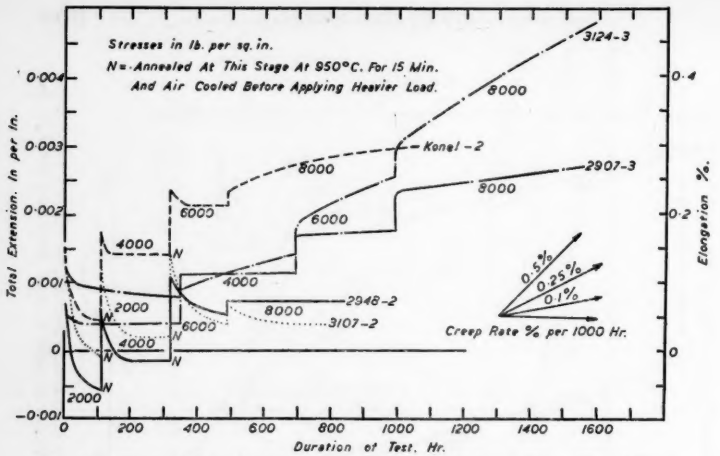


FIG. 11.—Creep Characteristics of Nickel-Cobalt-Iron Base Konel-Type Alloys at 600° C. and 2000, 4000, 6000 and 8000 lb. per sq. in.

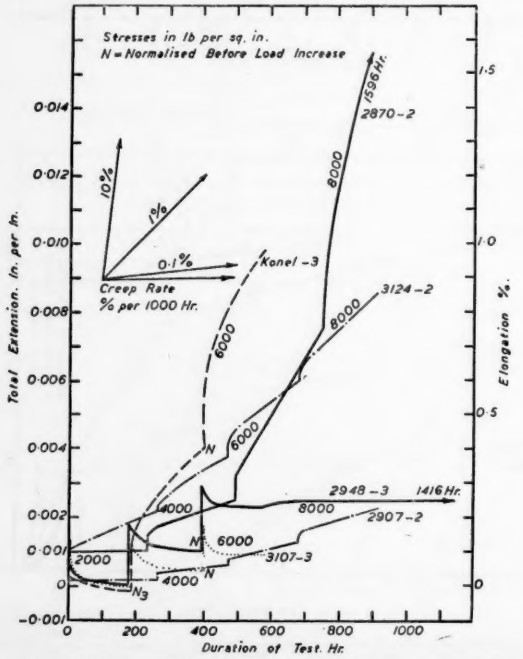


FIG. 12.—Creep Characteristics of Nickel-Cobalt-Iron Base Konel-Type Alloys at 700° C. and 2000, 4000, 6000 and 8000 lb. per sq. in.

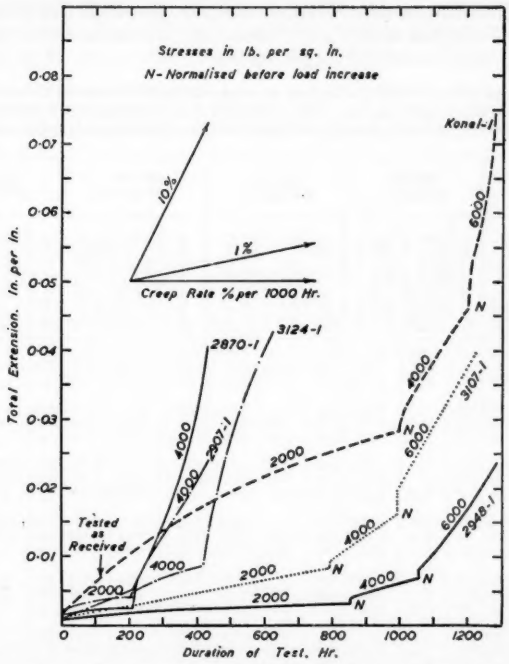


FIG. 13.—Creep Characteristics of Nickel-Cobalt-Iron Base Konel-Type Alloys at 800° C. and 2000, 4000 and 6000 lb. per sq. in.

In order to economise space and to facilitate ready comparison, the complete deformation history at constant temperature of each of the three classes of alloys has been drawn on one chart. Thus, Figs. 5, 6 and 7, respectively, illustrate the resistance to deformation at 600°, 700° and 800° C. of all the stainless 18/8 steels and nichrome, as listed in Table II. In the figures *N* denotes that the test rod was normalised from 950° C. before continuing the test at the next greater load. Since this procedure removed part of the strain-hardening, the subsequent initial strain on reloading was much greater than in the majority of tests where the load increase was made without intermediate annealing. Furthermore, the strain-time curve approximates to a linear relationship much more rapidly without intermediate annealing.

At 600° C. there is a wide difference in the behaviour of the stainless steels of " similar " chemical composition. Low negative rates of creep were recorded for some of the alloys at 2000 lb. per

TABLE II.—*Deformation Data at 250 Hr. for 18/8 Stainless Steels and Nichrome at 600°, 700° and 800° C. under Loads of 2000, 4000, 6000 and 8000 lb. per sq. in.*

After normalising at 950° C. the test at each temperature recorded was started with 2000 lb. per sq. in. Subsequently load increments were applied to the same specimen, usually without intermediate heat treatment.

Stress:		2000 lb. per sq. in.			4000 lb. per sq. in.			6000 lb. per sq. in.			8000 lb. per sq. in.		
Alloy Designation.	Temperature of Test. ° C.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.
LE -5	600	368	−0·02	0·020	330	0	0·06	388	0	0·07	417	0	0·105
-4	700	263	0	0·09	209	0·13	0·09	209	0·25	0·14	238	0·86	0·35
	800	215	0·46	0·285	214	1·05	0·37	86 *f*	10·0 [1]	1·77 *a*	...	...	...
AMK-3	600	368	−0·02	0·03	330	0	0·08	388	0	0·12	417	0·015	0·15
-2	700	263	−0·04	0·07	209	0·05	0·08	209	0·35	0·195	238	2·25	0·69
-1	800	215	0·26	0·17	214	0·80	0·33	219	24·0 [2]	7·7 *a*	...	...	...
302*C* -4	600	342	0·04	0·105	348	0·09	0·115	297	0·19	0·16	570	0·42	0·245
-3	700	263	0	0·09	209	0·13	0·125	209	0·38	0·21	238	2·90	0·82
-2	800	215	0·52	0·33	214	3·0	1·24	219	44·5 [3]	12·4 *a*	...	...	...
303*C* -3	600	368	−0·03	0·005	330	0	0·04	388	0	0·07	417	−0·03	0·085
-2	700	263	−0·07	−0·002	209	0·08	0·07	209	0·24	0·135	238	1·0	0·38
-1	800	210	0	0·055	210	1·28	0·565	209	19·4 [4]	4·73 *a*	...	...	...
18/8 -2	600	103	0	−0·007	206*	0·05	0·085	185*	0·10	0·155	342	0·04	0·14
-3	700	185	0	0·13	214*	0·15	0·31	180*	0·80	0·49	842	1·04	0·49
-1	800	814	0·35	0·24	168*	1·75	0·685	215* *f*	14·5 [5]	5·15 *a*	...	...	...
Ni- -2	600	103	0	0·05	206*	0·06	0·18	174*	0·10	0·215	937	0·10	0·13
chrome-3	700	185	0·28	0·205	214*	1·65	0·615	180*	4·4 [6]	1·05 *a*	...	...	...
-1	800	763	6·1 [4]	1·725	76*	53·3 [6]	7·68 *a*	...	...	...	...	...	...

* Annealed immediately before test (15 min. at 950° C. and air-cooled). Minimum (1) after 18 hr., (2) at start of test, (3) after 60 hr., (4) after 100 hr., (5) after 70 hr., (6) after 12 hr.
a Elongation, %, recorded is after hours of test indicated.
f Fractured at hours of test indicated.

sq. in. At 4000 lb. per sq. in. the creep rates were zero or at least very small, and at 6000 and 8000 lb. per sq. in. the difference in resistance to deformation was increasingly marked. Thus, at 8000 lb. per sq. in., where the test had run for about 1500 hr., the creep rates range from zero (or slightly negative) for the selenium-bearing alloy to 0·4% per 1000 hr. at 250 hr. (or 1240 hr. total) for selenium-free 302*C* stainless steel. At the end of the test on 302*C* the creep rate had fallen to 0·38% per 1000 hr. at 1550 hr. total.

At 700° C. a negative or zero creep again obtains with 2000 lb. per sq. in. and the maximum difference in behaviour found with 8000-lb. per sq. in. stress shows a creep rate per 1000 hr. ranging from 0·86 to 2·9%. It is of interest to note that the order of resistance to deformation at 600° C. is retained at 700° C. At 800° C. the creep rates obtained with 2000 lb. per sq. in. are reasonably

TABLE III.—*Deformation Data at 250 Hr. for Low-Nickel Chromium Alloys and Silchrome at 600°, 700° and 800° C. under Loads of 2000, 4000, 6000 and 8000 lb. per sq. in.*

After normalising at 950° C. the test at each temperature recorded was started with 2000 lb. per sq. in. Subsequently load increments were applied to the same specimen, usually without intermediate heat treatment.

Stress :		2000 lb. per sq. in.			4000 lb. per sq. in.			6000 lb. per sq. in.			8000 lb. per sq. in.		
Alloy Designation.	Temperature of Test. °C.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.
A33K-3	600	368	0·4	0·28	330	1·0	0·51	388	3·6	1·19	417	11·8	3·27
-2	700	234	3·0	1·96	201*f*	42·5[1]	26*a*	...	...	...	...	...	...
-1	800	215	90·0[2]	26*a*	...	...	...	...	...	...	...	...	...
A66K-3	600	368	0·22	0·155	330	0·42	0·34	388	4·5	1·46	417	33·2	8·45
-2	700	189	7·7	2·4	91	237[3]	31*a*	...	...	...	...	...	...
-1	800	107	92·0[4]	11·3*a*	...	...	...	...	...	...	...	...	...
329C-3	600	368	0·14	0·08	330	1·8	0·64	388	3·5	1·22	417	4·6	1·59
-2	700	234	3·5	2·25	258	12·2[5]	3·5	262	58·5[6]	32·1	...	...	...
-1	800	210	51·0	6·5	74	425[3]	40*a*	...	...	...	...	...	...
14% Cr-2	600	212	0·7	0·30	170[6]	1·75	0·9	186[6]	5·35	2·07	937	8·75[6]	2·52
-3	700	120	6·7	2·60	...	...	...	...	...	...	...	...	...
-1	800	177*r*	335[3]	62·8*a*	...	...	...	...	...	...	...	...	...
Sil- -2	600	196	0·68	0·45	174[6]	1·75	0·75	186[6]	10·0	3·02	...	...	...
chrome-3	700	185	1·6	0·92	52[6]	53·5[7]	4·10*a*	...	...	...	...	...	...
-1	800	47	470[6]	39·8*a*	...	...	...	...	...	...	...	...	...

[6] Annealed immediately before test (15 min. at 950° C. and air-cooled). Minimum after (1) 20 hr., (2) 25 hr., (3) 5 hr., (4) 40 hr., (5) 1000 hr., (6) 10 hr., (7) 52 hr., (8) 15 hr.
a Elongation, %, recorded is after hours of test indicated.
f Fractured at hours of test indicated.
r Test conducted on specimen in as-received condition.

comparable—0·26–0·56%. All the alloys are too weak to merit testing at 8000 lb. per sq. in. stress. At 600° C. the strength of nichrome is comparable to that of the stainless steels, but as the temperature increases the nickel-chromium alloy becomes markedly weaker than the steels.

On account of the heavy shank the rates for alloy *AMK* should be slightly higher than those recorded, for strict comparison with the other alloys.

Data similar to those discussed are given in Figs. 8, 9 and 10 for low-nickel iron-chromium alloys. However, these alloys are so much weaker at temperatures above red heat that stresses of 6000 and 8000 lb. per sq. in. were of interest only at the lowest test temperature, 600° C., where any marked difference in high-temperature strength is not revealed below a stress of 8000 lb. per sq. in. In general, the 12% chromium alloy appears to be stronger than the 18% chromium alloy. In alloy *329C*, 24% chromium, the

TABLE IV.—*Deformation Data at 250 Hr. for Konel-Type Alloys at 600°, 700° and 800° C. under Loads of 2000, 4000, 6000 and 8000 lb. per sq. in.*

After normalising at 950° C. the test at each temperature recorded was started with 2000 lb. per sq. in. Subsequently load increments were applied to the same specimen, usually without intermediate heat treatment.

Stress:		2000 lb. per sq. in.			4000 lb. per sq. in.			6000 lb. per sq. in.			8000 lb. per sq. in.		
Alloy Designation.	Temperature of Test. °C.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr. %.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.	Hours at Test.	Creep Rate, % per 1000 Hr. at 250 Hr.	Total Elongation at 250 Hr. %.
Konel-2	600	107	0	0·045	206*	0	0·125	174*	0	0·125	570	0·08	0·13
-3	700	185	0	−0·01	214*	0·97	0·525	180*	1·71	0·755	...	...	...
-1	800	1003 *rh*	3·57	1·21	202*	6·5	2·16	80*f*	22·0 [1]	2·9 *a*	...	...	...
2948-2	600	107	0	−0·07	206*	0	0·065	174*	0	0·11	348	0	0·085
(*K42B*)-3	700	180	0	0	214*	0	0·12	180*	−0·7*	1·17	842	0	0·09
-1	800	855 *k*	0·5	0·20	202*	1·45	0·47	231*	5·35 [3]	1·73 *a*	...	...	...
3107-2	600	107	0	−0·05	206*	0	0·045	174*	−0·17	0·07	297	−0·03	0·06
-3	700	185	0	−0·01	214*	0	0·065	180*	0	0·09	...	...	...
-1	800	793 *m*	0·9	0·345	202*	3·2	0·965	231*	8·35 [4]	2·4 *a*	...	...	...
2907-3	600	342	−0·02	0·08	348	0	0·05	297	0·02	0·105	570	0·09	0·14
-2	700	263	0	0·02	209	0·1	0·07	209	0·22	0·11	238	0·33	0·165
-1	800	214	2·0	0·59	219	7·7 [5]	1·93 *a*	...	...	...	...	...	...
2870-2	700	234	0·02	0·10	258	0·33	0·165	262	1·61	0·495	842	5·8 [2]	1·67
-1	800	214	0·50	0·285	219	11·4 [3]	3·7 *a*	...	...	...	...	...	...
3124-3	600	342	0	0·04	328	0·16	0·11	297	0·22	0·145	570	0·31	0·19
-2	700	263	0·53	0·21	209	0·58	0·20	209	0·61	0·275	238	0·88	0·33
-1	800	210	0·43	0·43	210	1·7	0·57	209	8·6	3·8	...	...	...

* Annealed immediately before test (15 min. at 950° C. and air-cooled). Minimum after (1) 20 hr., (2) 80 hr., (3) 30 hr., (4) 100 hr., (5) 60 hr.
a Elongation, %, recorded is after hours of test indicated.
f Fractured at hours of test indicated.
r Test conducted on specimen in as-received condition.
h 2225, *k* 2250, *m* 2230 lb. per sq. in.

added high-temperature strength is probably due to the presence of 3·4% of nickel and 1·6% of molybdenum. Silchrome exhibits the least deformation resistance.

The information on the konel-type alloys (Figs. 11, 12 and 13) is unusual, since the alloys age-hardened at the temperature of test, and thus constitutional change resulted in a marked contraction of the test bar. The amount of this contraction is sufficiently great to mask completely any creep extension, and even to provide a figure as "negative creep." Unfortunately, many of the alloys were renormalised before each load increment, so that the contraction due to structural changes is over-emphasised. However, it is interesting to note that alloy 3107, 500 hr. after a final normalising treatment, even with a load of 8000 lb. per sq. in. at 600° C., continues to exhibit negative creep.

The decrease in high-temperature strength at 700° and 800° C. resulting from the omission of ferro-titanium in this class of alloys is well shown in the low resistance to deformation of alloy 2870 (*K42B* without titanium but with the usual iron content). It is of particular interest to compare the high-temperature strength with the recently published data on various other properties of these same alloys. [6]

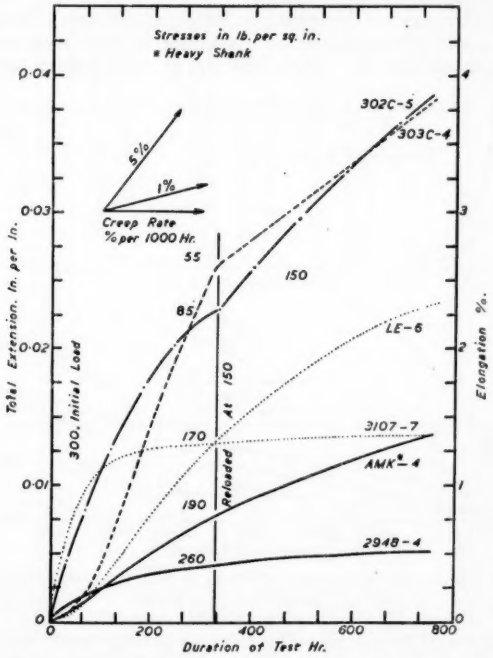


FIG. 14.—Creep Characteristics of Alloys at 1000° C. and 300 and 150 lb. per sq. in.

A few data were obtained on the relative deformation characteristics of some of the stronger alloys at 1000° C. under low stress. On account of the appreciable elongation of the alloys at 300 lb. per sq. in., relaxation of the spring loading resulted in a progressively marked decrease in stress. The ultimate stress after about 350 hr. is recorded in Fig. 14; at this point the load was reduced to 150 lb. per sq. in. and maintained for a further 400 hr.

It should be stated that the results of this series of tests were largely influenced by the resistance of the various alloys to oxida-

tion. Alloy 2948 (*K42B*) appears to be the strongest alloy at 1000° C., but the behaviour of alloy 3107 is unusual. Either strain-hardening or some constitutional change in the alloy results in a profoundly increased resistance to creep after about 150 hr. at temperature. The rapid oxidation of the 18/8 stainless materials compared with the light scaling of the *K42B* type of alloys was very clearly shown. This fact is of importance in a general consideration of high-temperature serviceability.

In an attempt to differentiate between resistance to deformation and resistance to oxidation a number of tests were conducted in hydrogen at 950° C. After 1600 hr. at temperature very slight

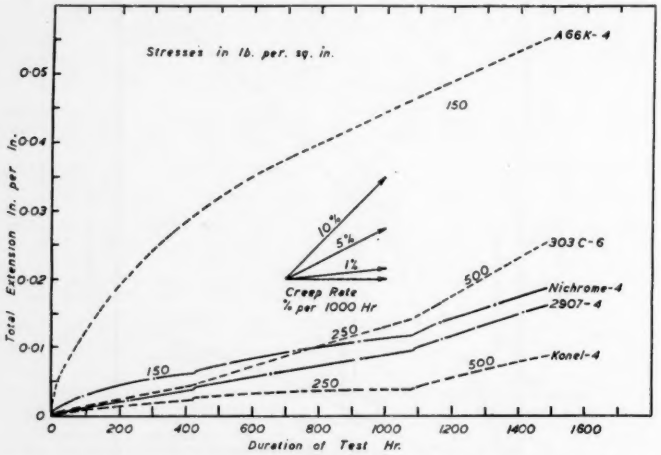


FIG. 15.—Creep Characteristics of Alloys at 950° C. in Hydrogen, and at 150, 250 and 500 lb. per sq. in.

oxidation could be noted. The most surprising result was obtained with the basic konel alloy, which exhibited greater strength than either of the modified chromium-bearing konel-type alloys (Fig. 15). The low resistance to deformation of the 18% chromium ferritic alloy (*A66K*) did not merit testing above 150 lb. per sq. in.

While no tests were conducted for the specific purpose of examining the reproducibility of the test values, several tests were run which afford data for comparison purposes. In Fig. 16 are shown elongation-time curves at 800° and at 700° C.

At 800° C. *LE*–1 and *LE*–3 are strictly comparable duplicate runs of similar stainless 18/8 test bars. Sample *LE*–2 was tested first at 4000 lb. per sq. in. and naturally, at this stress, shows a higher creep rate than the other two specimens.

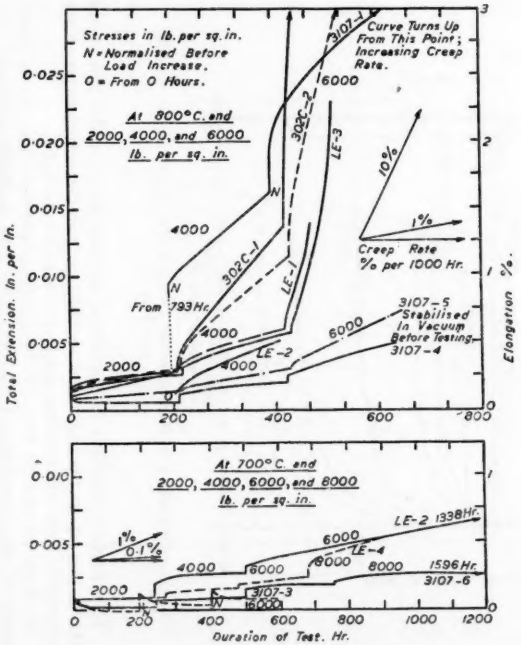


FIG. 16.—Repeat Tests of Alloys.

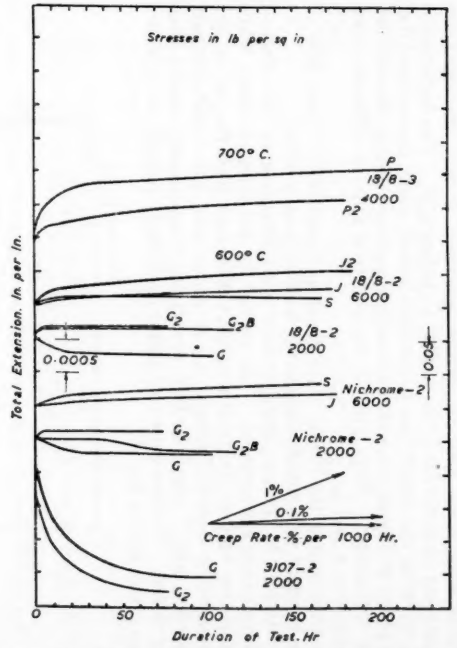


FIG. 17.—Repeat Runs of Alloys at 700° and 600° C.

In the case of alloy 3107, specimen 4 was tested after an initial normalising from 950° C., while specimen 5 was stabilised by annealing *in vacuo* for 70 hr. at 850° C. before test. The higher rate of creep of the latter was to be anticipated, since contraction due to phase precipitation was practically completed during the stabilising treatment. Alloy 3107–1 was selected from a different melt from Nos. 4 and 5.

Considering the higher rates of creep, alloys 302*C*–1 and 302*C*–2 are thought to compare reasonably well with each other.

At 700° C. the two tests on alloy 3107 demonstrate the effect of intermediate normalising. The curves for *LE* stainless steel, while indicating almost identical results at 2000 and 4000 lb. per sq. in., diverged at 6000 lb. per sq. in., at which load No. 2 rod, initially tested at 800° C. under 4000 lb. per sq. in., is apparently weaker than No. 4 rod. Repeat runs extending over short periods of time are also presented in Fig. 17.

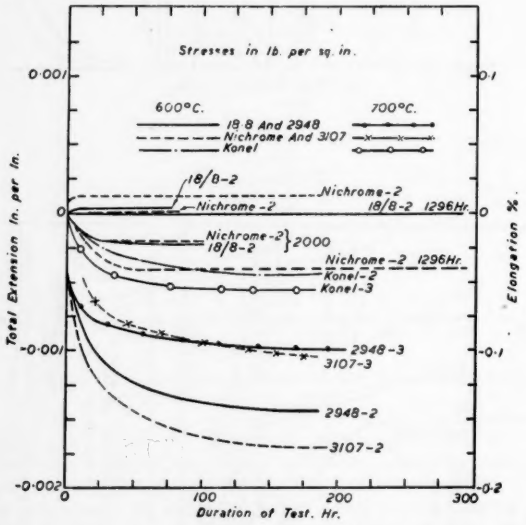


FIG. 18.—Dilatation of Alloys under Load of 100 lb. per sq. in. at 600° and 700° C.

The marked negative dilatation of several alloys under low stress (100 lb. per sq. in.) is indicated in Fig. 18. In the konel-type alloys apparently this contraction may approximate to 0·2%.

In Figs. 19 and 20 two sets of comparative data are given which permit of the correlation between single and multiple loading.

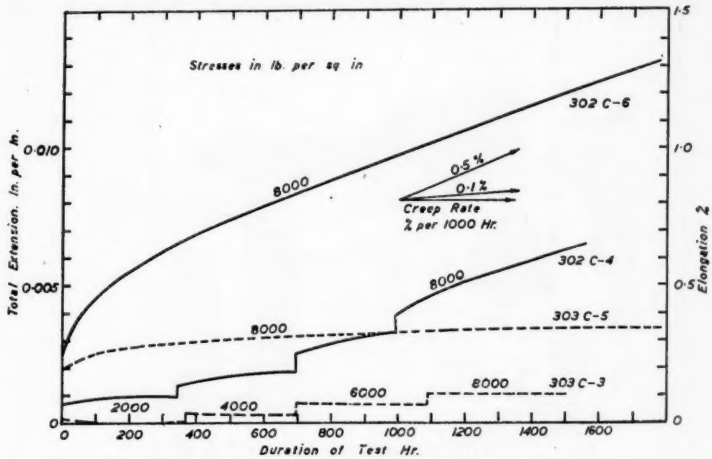


FIG. 19.—Creep Characteristics of Alloys at 600° C. under Single and Multiple Loading.

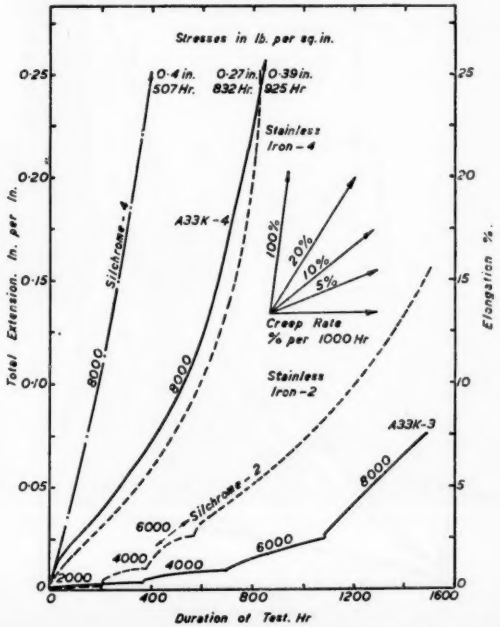


FIG. 20.—Creep Characteristics of Alloys at 600° C. under Single and Multiple Loading.

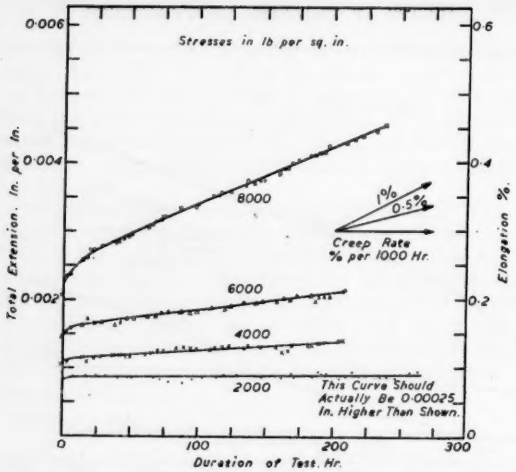


FIG. 21.—Distribution of Data. Alloy *LE*–4 at 700° C.

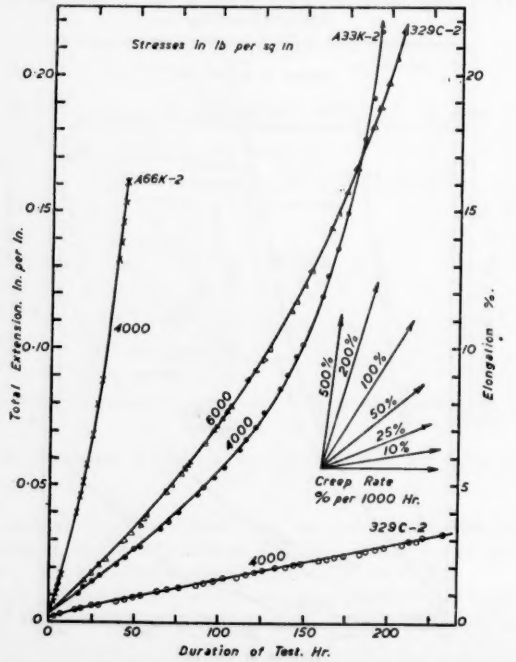


FIG. 22.—Distribution of Data. Low-nickel type alloys at 700° C.

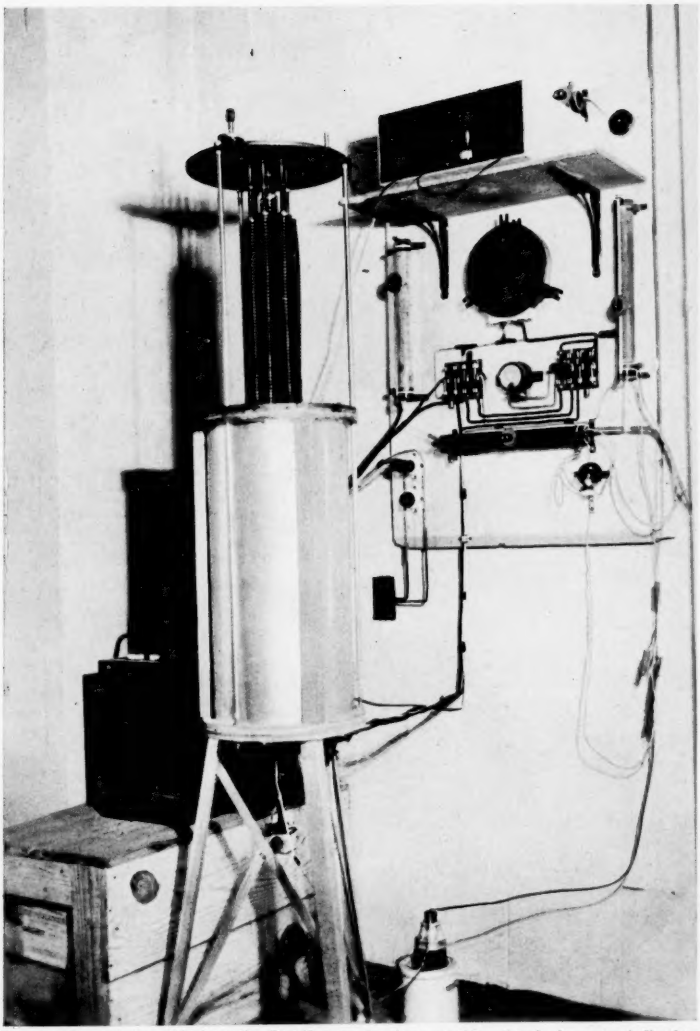


FIG. 23.—General View of Deformation Test Furnace showing control board and micrometer indicating device.

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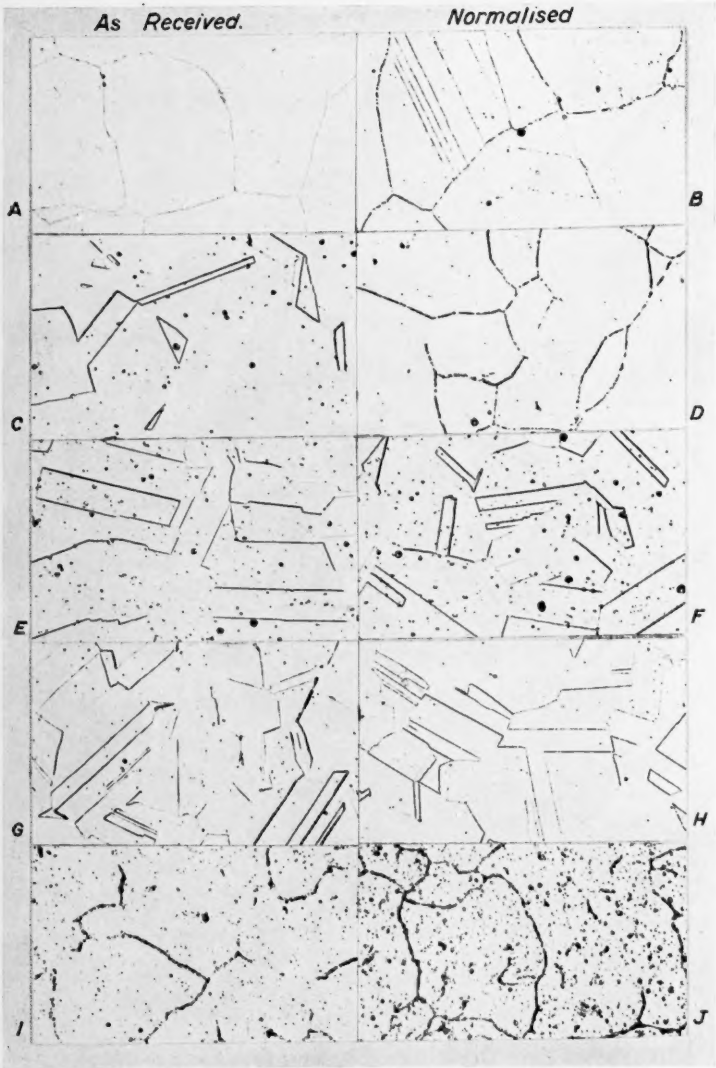
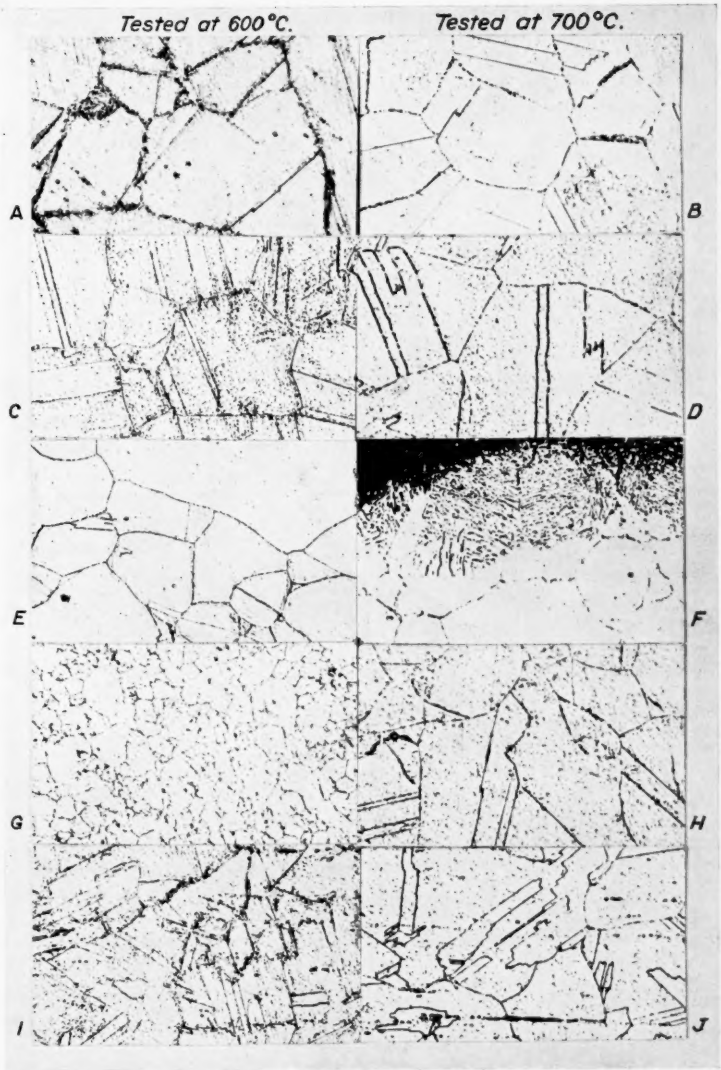


As-received : **A,** *LE.* **C,** *AMK.* **E,** 18/8. **G,** 302*C* (*A*). **I,** 303*C* (*A*).
Normalised : **B,** *LE.* **D,** *AMK.* **F,** 18/8. **H,** 302*C* (*A*). **J,** 303*C* (*A*).

FIG. 24.—Stainless 18/8 Steels As-received and Normalised. Electrolytic etch, 10% oxalic acid in water. × 300.

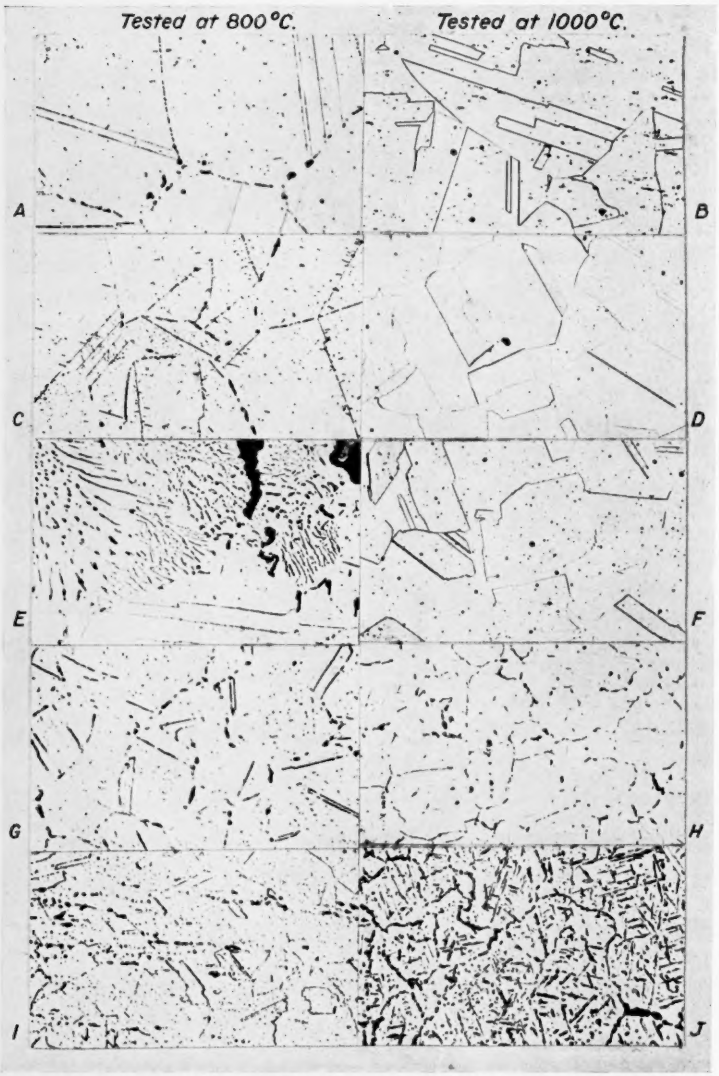
[*Austin & Nickol.*



A, B, *LE*, tested at 600°, 700° C. **C, D,** *AMK* tested at 600°, 700° C. **E, F,** 18/8 tested at 600°, 700° C. **G,** 302*C* (*B*) tested at 600° C. **H,** 302*C* (*A*) tested at 700° C. **I, J,** 303*C* (*A*) tested at 600°, 700° C.

FIG. 25.—Stainless 18/8 Steels Tested at 600° and 700° C. Electrolytic etch, 10% oxalic acid in water. × 300.

[*Austin & Nickol.*



A, B, *LE* tested at 800°, 1000° C. **C, D,** *AMK* tested at 800°, 1000° C. **E,** 18/8 tested at 800° C. **F,** 18/8, 400 hr. at 1000° C., unstressed. **G,** 302*C* (*A*) tested at 800° C. **H,** 302*C* (*B*) tested at 1000° C. **I,** 303*C* (*A*) tested at 800° C. **J,** 303*C* (*B*) tested at 1000° C.

FIG. 26.—Stainless 18/8 Steels Tested at 800° (× 300) and 1000° C. (× 80). Electrolytic etch, 10% oxalic acid in water. **J** etched first electrolytically in 1 : 3 : 2 : 2 HNO_3/HCl/acetic-acid/water.

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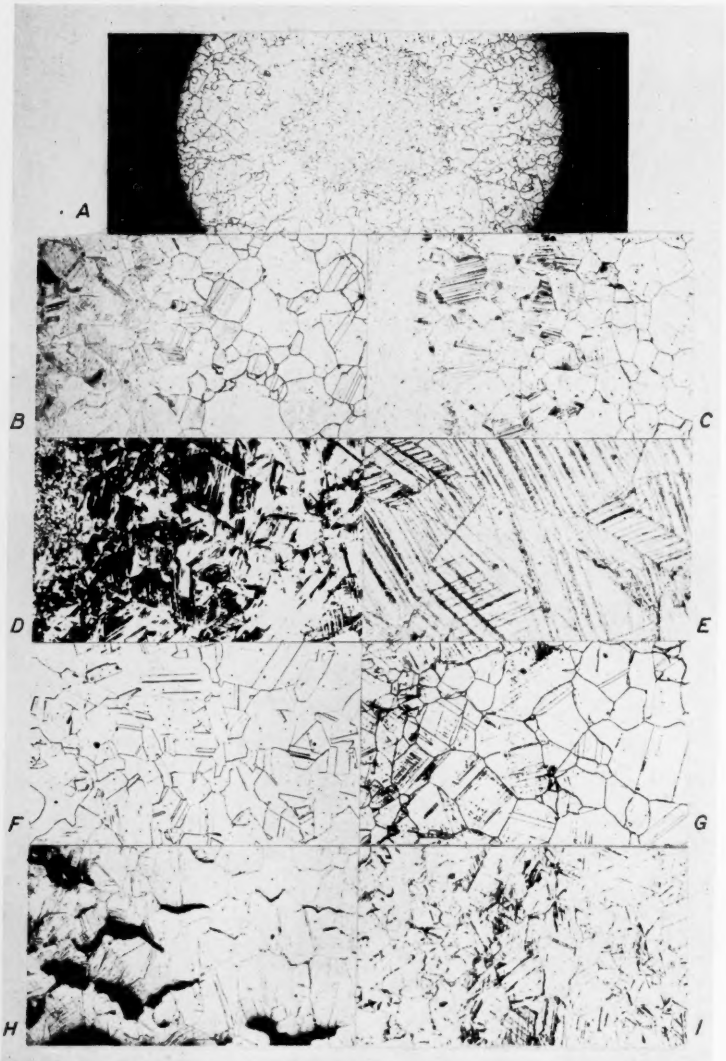
A–D : Nichrome. **A,** as-received. **B,** normalised. **C,** tested at 800° C. **D,** 400 hr. at 1000° C., unstressed. Electrolytic etch, 2½% oxalic acid in water. × 300.
E, *AMK* tested at 600° C. × 300. **F,** *LE* tested at 600° C. near edge (Fig. 28*C*). × 300. **G,** *AMK*, tested at 600° C. × 1600. **H,** 303*C* (*A*) tested at 600° C. × 300. **I,** 302 *C* (*B*) tested at 1000° C. × 80. **J,** 303*C* (*A*) tested at 1000° C. Etched 10% oxalic acid. × 80.

FIG. 27.—Nichrome and Hot Shanks of Stainless 18/8 Steels.

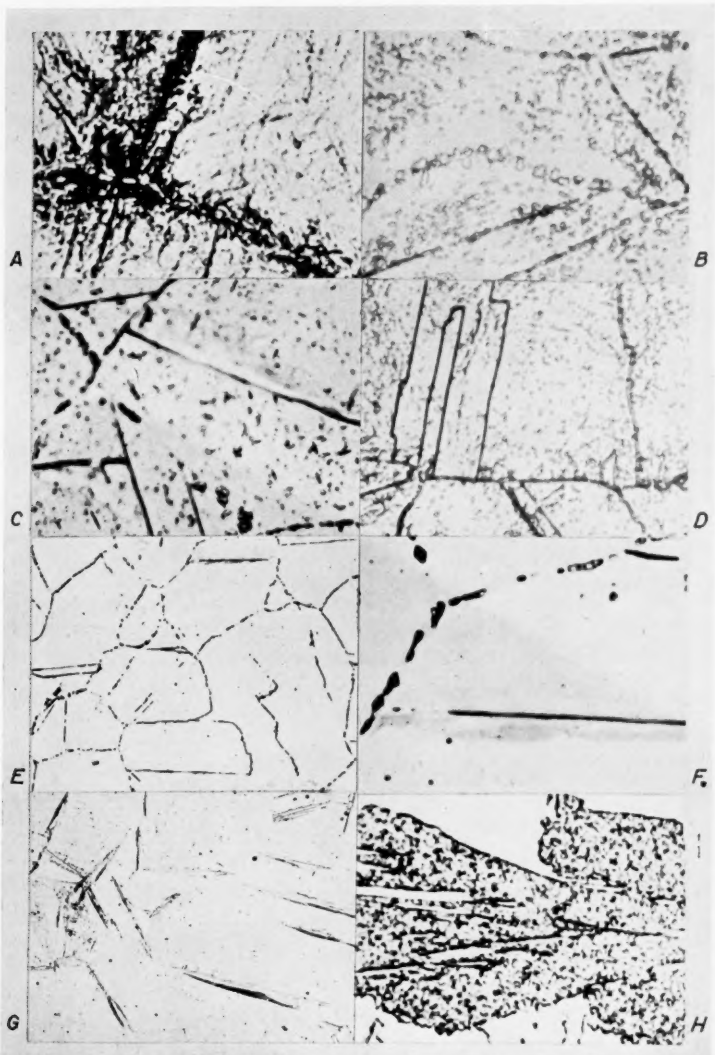
[*Austin & Nickol.*



A, 18/8 tested at 600° C. × 20. **B,** *LE* as-received, edge. × 80. **C,** *LE* normalised, edge. × 80. **D,** *LE* tested at 600° C., hot shank. × 80. **E,** *LE* tested at 600° C., edge. × 300. **F,** *AMK* as-received, edge. × 80. **G,** *AMK* normalised, edge. × 80. **H,** *LE* fractured at 800° C. × 80. **I,** *AMK* edge hot shank at 700° C. Etched 10% oxalic acid. × 80.

FIG. 28.—Stainless 18/8 Steels.

Austin & Nickol.



A, *LE* tested at 600° C. × 2000. **B,** *AMK* tested at 600° C. × 1800. **C,** 302*C* (*A*) tested at 700° C. × 1500. **D,** 303*C* (*A*) tested at 600° C. × 1600. **E,** 18/8 hot shank at 700° C. × 300. **F,** as **E,** oblique illumination. × 2000. **G,** *LE* hot shank at 1000° C. × 80. **H,** as **G,** Fry's etching reagent. × 2000.

FIG. 29.—Stainless 18/8 Steels. Electrolytic etch, 10% oxalic acid.

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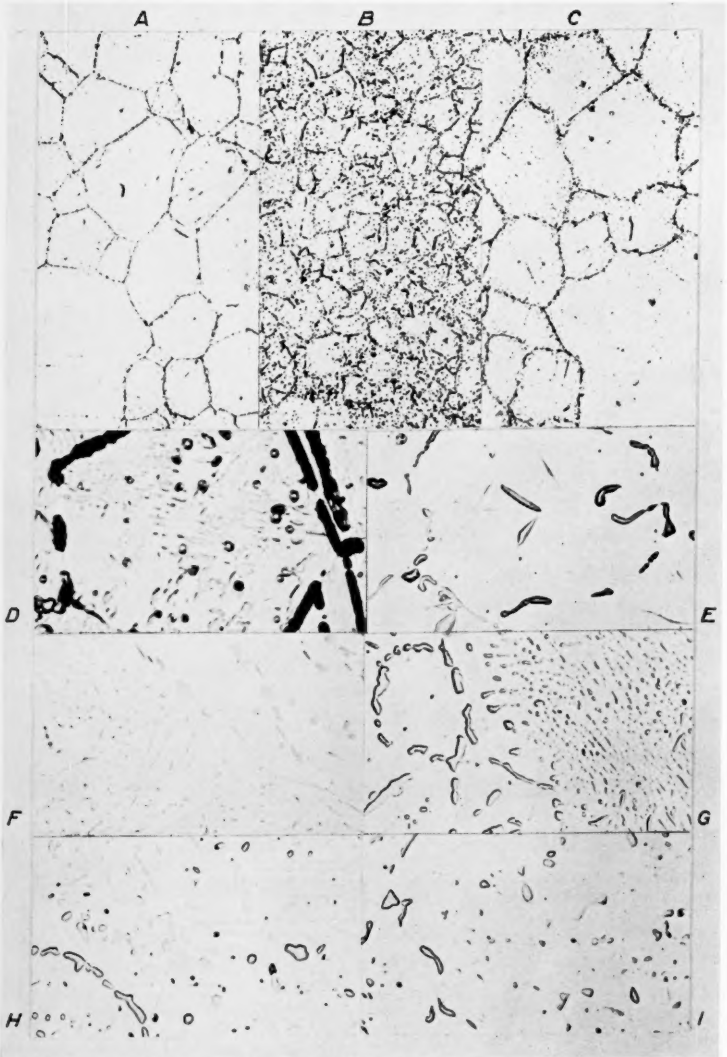
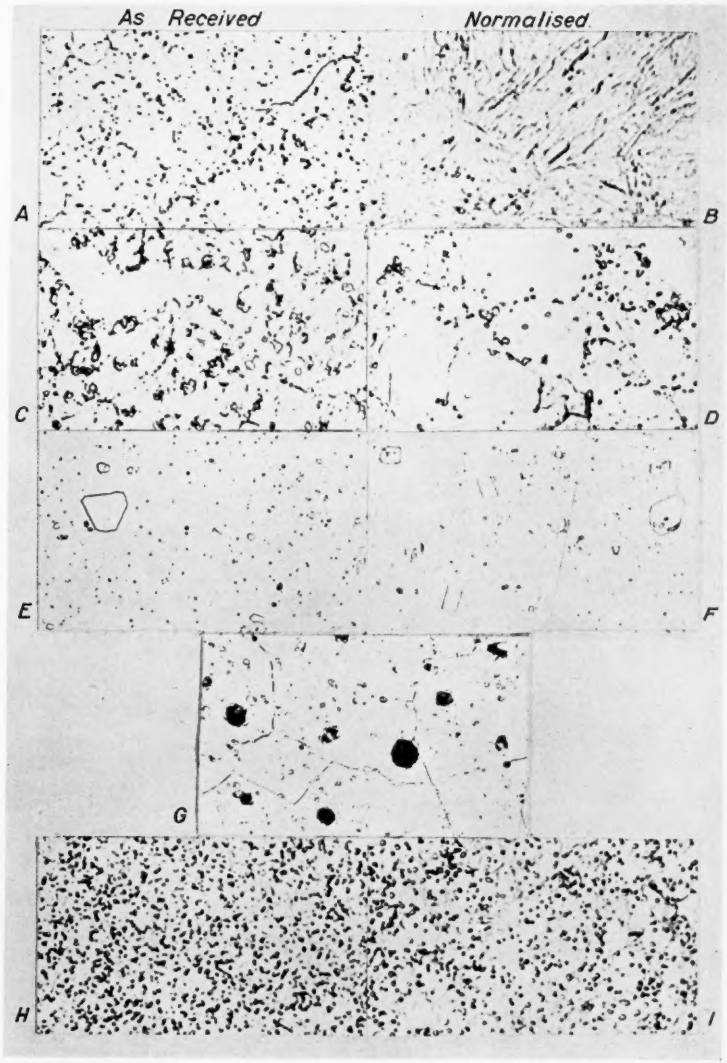


A, 302*C* (*A*) normalised and annealed 600° C. × 300. **B,** 302*C* (*B*) normalised and annealed. × 300. **C,** 302*C* (*B*) quenched 1080° C., normalised, annealed 600° C. × 300. **D,** 302*C* (*A*) tested at 800° C. (deep etch). × 1000. **E,** 302*C* (*B*) tested at 1000° C. × 300. **F,** *AMK* tested at 1000° C. × 600. **G, H,** 303*C* (*B*) tested at 1000° C. × 300. **I,** 303*C* (*B*) tested at 950° in hydrogen. × 300.

FIG. 30.—Stainless 18/8 Steels. **A–D,** 10% oxalic acid etch. **E–I,** unetched.

[*Austin & Nickol.*



As received: **A**, *A33K*. × 1000. **C**, *A66K*. × 1000. **E**, 329*C*. × 300. **H**, silchrome. × 1000.
Normalised: **B**, *A33K*. × 1000. **D**, *A66K*. × 1000. **F**, 329*C*. × 300. **G**, 329*C*, deep etch. × 300. **I**, silchrome. × 1000.

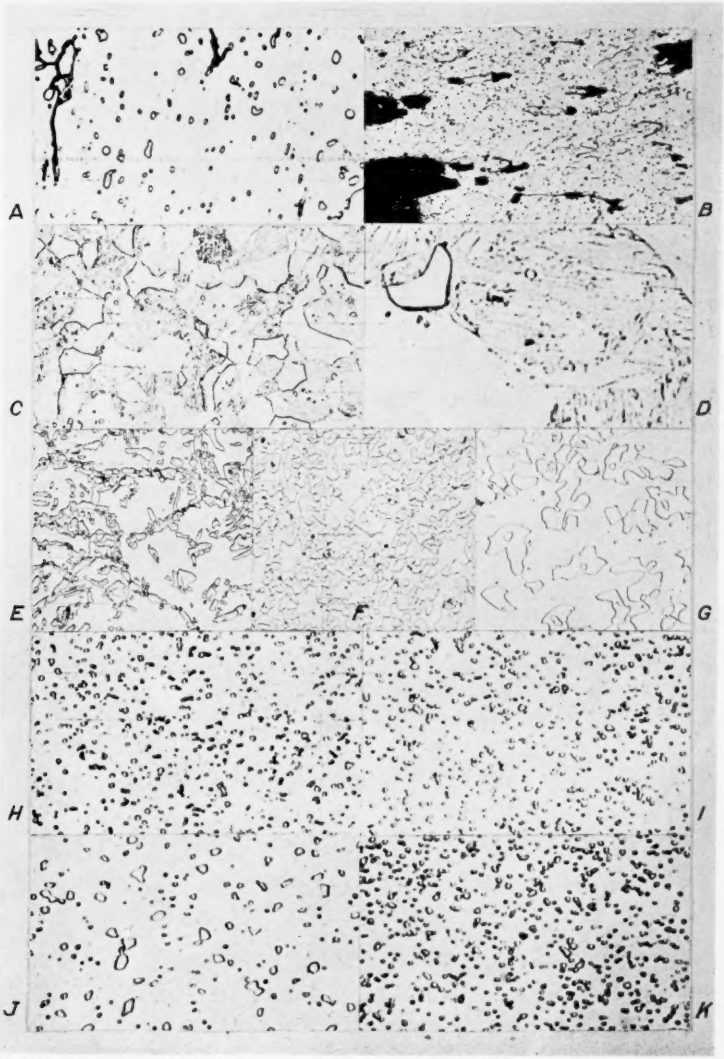
FIG. 31.—Chromium-Iron Alloys As-received and Normalised. Etching reagents: *A33K* and silchrome, 1 : 2 : 2 : 1 HNO_3/HCl/glycerine/acetic-acid. *A66K*, 75% HCl in alcohol. 329*C*, electrolytic etch, 2½% oxalic acid in water.

[*Austin & Nickol.*

A–E, *A33K*, etched in 1 : 2 : 2 : 1 HNO_3/HCl/glycerine/acetic-acid. **F–K,** *A66K*, etched in 75% HCl in alcohol. **A,** *A33K*, tested at 600° C. **B,** *A33K* tested at 700° C. **C,** *A33K* hot shank 700° C. **D,** *A33K* tested at 800° C. **E,** *A33K* hot shank 800° C. **F, H, J,** *A66K* tested at 600°, 700° and 800° C. **G, I, K,** *A66K* hot shank 600°, 700° and 800° C.

FIG. 32.—Chromium-Iron Alloys. Tested at 600°, 700° and 800° C. × 1000.

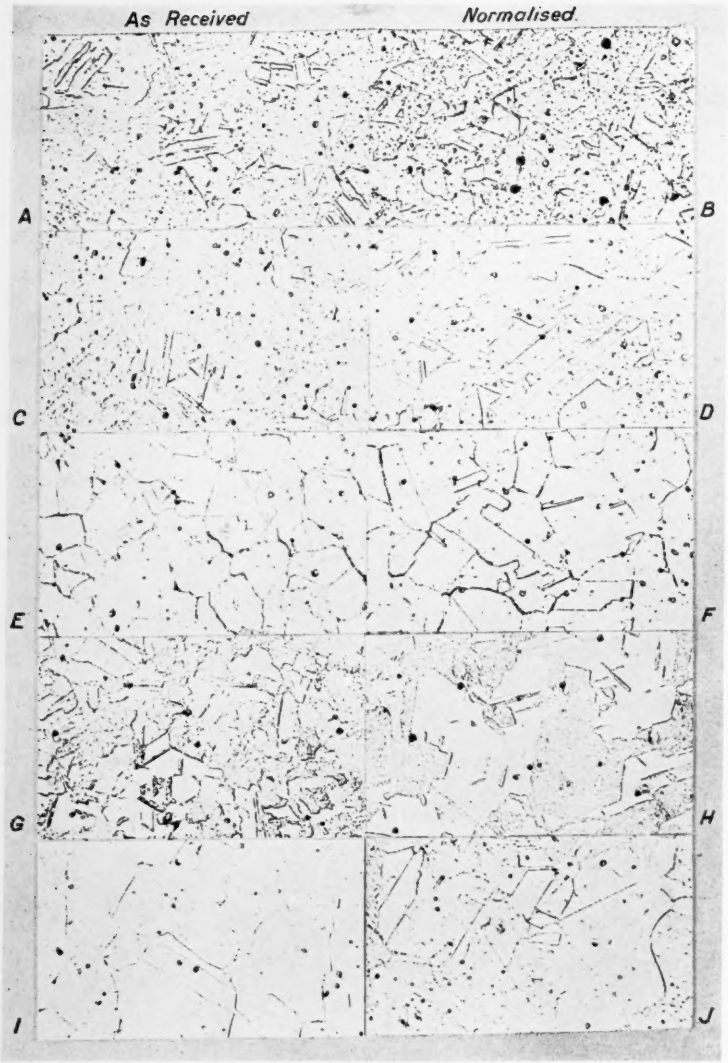
[*Austin & Nickol.*



A, *A33K* near fracture at 700° C. × 1000. **B,** *A66K* fracture at 800° C. × 100. **C,** *A66K* tested at 950° C. in hydrogen. × 100. **D,** same as **C.** Etched in 75% HCl in alcohol. × 1000. **E, F, G,** 329*C* tested at 600°, 700° and 800° C. Etched electrolytically in 2½% oxalic acid. × 300. **H, I, J,** silchrome tested at 600°, 700° and 800° C. × 1000. **K,** silchrome, hot shank, 800° C. Etched, 1 : 2 : 2 : 1 HNO_3/HCl/glycerine/acetic-acid (also *A33K*). × 1000.

FIG. 33.—Chromium-Iron Alloys. Tested at 600°, 700° and 800° C. (950° C. in hydrogen.)

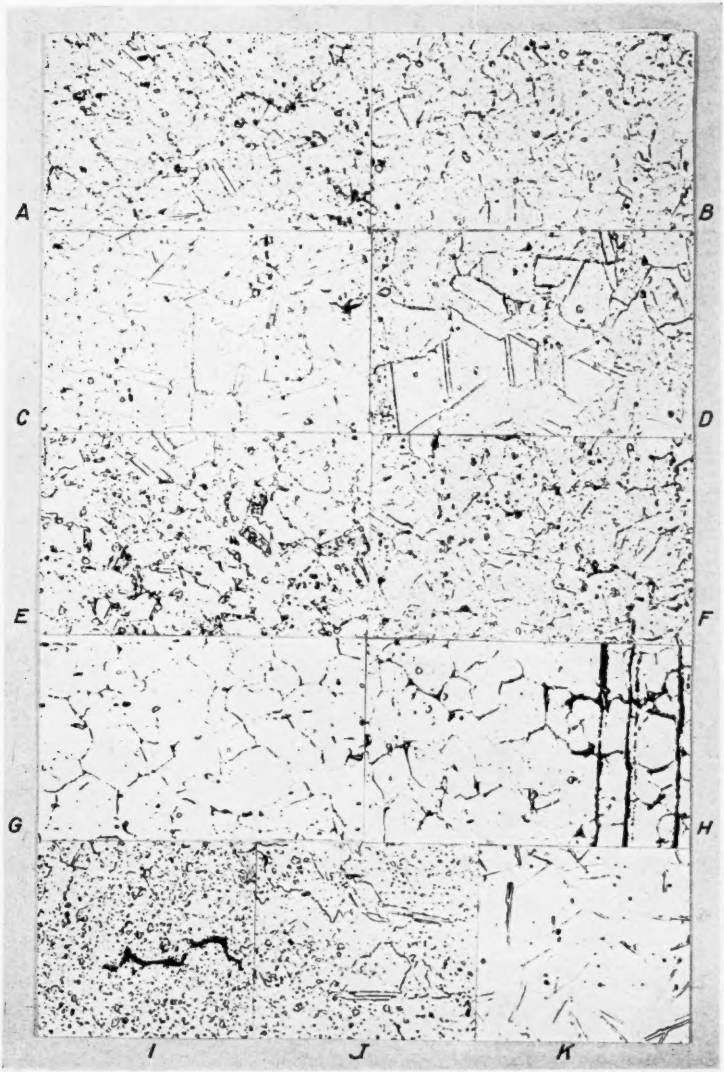
[*Austin & Nickol.*



As-received: **A,** 2948 (*K42B*). **C,** 3107 (cobalt, nickel). **E,** 2907 (tungsten; free from chromium). **G,** Konel. **I,** 3124 (cobalt, iron, titanium).
Normalised: **B,** 2948 (*K42*). **D,** 3107 (cobalt, nickel). **F,** 2907 (tungsten; free from chromium). **H,** Konel. **J,** 3124 (cobalt, iron, titanium). **A, B, C, D, G, H,** etched electrolytically in 1 : 4 : 1 : 1 HNO_3/HCl/acetic-acid/water plus 1½ g. cupric ammonium chloride per 100 c.c. of solution. **E, F, I, J,** etched electrolytically in above 1 : 4 : 1 : 1 solution.

FIG. 34.—Konel-Type Alloys As-received and Normalised. × 300.

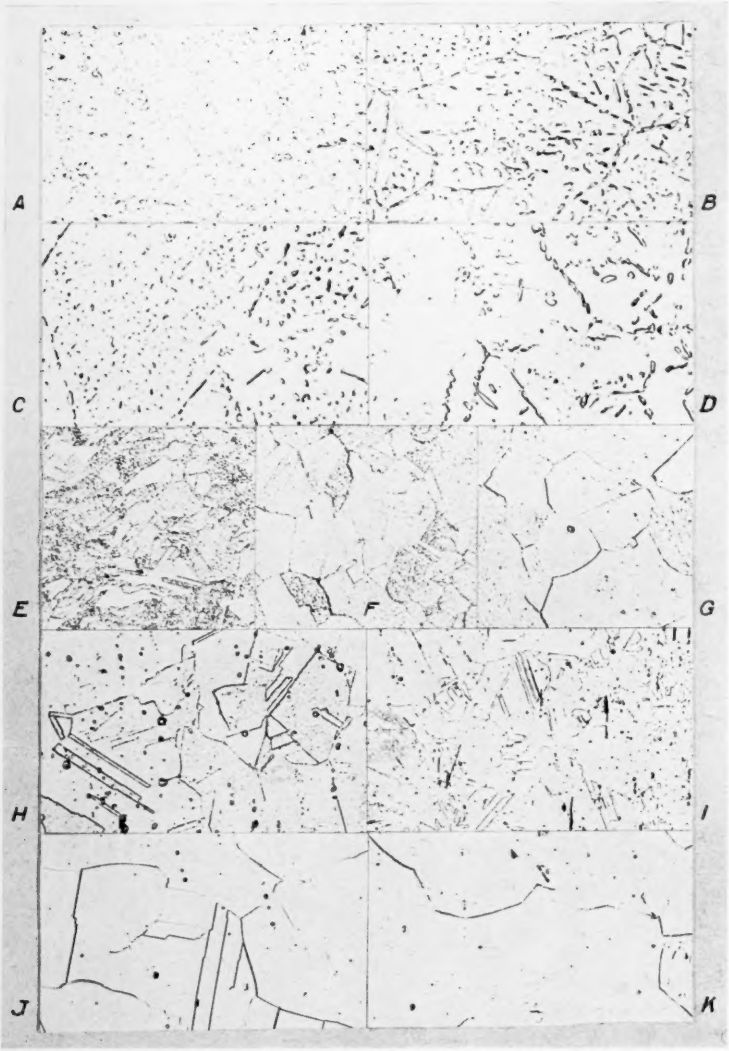
[*Austin & Nickol.*



A. C, E, 2948 tested at 600°, 700° and 800° C. **B, D, F,** 3107 tested at 600°, 700° and 800° C. **G, H, K,** 2907 tested at 600°, 700° and 800° C. **I, J,** 2870 tested at 700° and 800° C. Nos. 2948, 3107, 2870, etched electrolytically in 1 : 4 : 1 : 1 HNO_3/HCl/acetic-acid/water plus 1½ g. cupric ammonium chloride per 100 c.c. of solution. No. 2907, etched electrolytically in above 1 : 4 : 1 : 1 solution.

FIG. 35.—Konel-Type Alloys.

[*Austin & Nickol.*



A, B, C, 3124 tested at 600°, 700° and 800° C. **D,** 3124 hot shank at 800° C. × 1000. **E, F, G,** konel tested at 600°, 700° and 800° C. × 300. **H,** 2948 tested at 1000° C. × 300. **I,** 3107 tested at 1000° C. × 80. **J,** 2907 tested at 950° C. in hydrogen. × 300. **K,** konel tested at 950° C. in hydrogen. × 80. **A–D, J, K,** etched electrolytically in 1 : 4 : 1 : 1 HNO_3/HCl/acetic-acid/water. **E–I,** etched electrolytically in 1 : 4 : 1 : 1 solution plus 1½ g. cupric ammonium chloride per 100 c.c.

FIG. 36.—Konel-Type Alloys.

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In the type of test described in this paper one may expect a considerable scatter of the data, especially where very small rates of creep are in evidence. However, some typical data representing both low and high creep rates are shown in Figs. 21 and 22. Despite the scatter, it is usually possible to obtain a curve which may be considered to represent a fairly definite statistical average. Control of the room temperature where the tests are conducted would very materially reduce the scatter of the data.

PART II.—Microstructural Characteristics and General Correlation with Data Presented in Part I.

Abstract.

This part of the paper provides a metallographic study of the effect of temperature and stress on stainless 18/8 steels, chromium irons, and konel-type alloys. Details of the preparation of the samples and of the etching technique are described.

A comparison of the general structural features of the alloys includes the observation that stress plays an important rôle in the rate of precipitation and aggregation of a disperse phase, and hence in the high-temperature strength of alloys. There appears to be definite evidence that in chromium-iron alloys the rate of spheroidisation of the small amount of carbide present is markedly greater at the higher stresses.

An increase in the susceptibility to magnetism correlates with the decrease in strength and the increase in brittleness of the stainless 18/8 alloys.

In a general discussion of the investigation, diagrammatic pictures are presented to show (1) the marked relative superiority of austenitic stainless steels over ferritic chromium irons in their resistance to deformation at elevated temperatures, and (2) the comparative deformation rates of the three classes of alloys and their general distribution with respect to creep rate, stress and temperature.

In Part I. of this investigation data were presented on the deformation characteristics of the alloys at temperatures from 600° to 1000° C. obtained by means of a new type of equipment. While some attention has been given more recently to a correlation of microstructure with long-time deformation tests, relatively few data are available on high-temperature alloys, particularly at temperatures above red heat.

In the present part an effort has been made to present a comprehensive survey illustrating three main features :

(1) The effects of time and temperature on the microstructural changes in alloys.

(2) A correlation of the microstructures of alloys in the same class, with particular detailed reference to the behaviour of the stainless 18/8 steels.

(3) A general comparison of the difference in behaviour of the three classes of alloys studied.

The metallography of stainless 18/8 steels, ferritic chromium irons and konel-type alloys will be discussed in the sequence listed. A general discussion of the investigation will then follow.

Preparation of the Specimens for Metallography.

Comment should be made on the preparation of the specimens, by polishing and etching, for metallographic study. The polishing technique varied with the different alloys and much experimentation was necessary before a satisfactory method could be developed. All samples were mounted in bakelite *BM*45 or *BM*1529 before grinding.

The alloys were first prepared by grinding in the usual way on emery papers down to 000 grain. Grinding was then completed by using graphite as a lubricant on a final 000 paper.

The stainless steels and chromium irons were then polished on a billiard-cloth wheel, using levigated alumina, and then on a second wheel, using relevigated alumina. The final polish was effected on " selvyt," using a thin paste of magnesium oxide.

The konel type of alloys was not amenable to this treatment. Pitting was avoided by dry-polishing on wax wheels prior to the final polish on " selvyt." The first wax wheel was loaded with 600-grain alundum mixed with Dixon's No. 2 fine flake graphite. On the second wax wheel a mixture of 40% levigated alumina and 60% graphite was used.

A study of the etching problems associated with these semi-stainless alloys resulted in the development of a new etching technique. Much has been published on the metallography of stainless steels, but it was found that the method of etching recently suggested by Erhlinger [10] gave the most satisfactory results. This involved the use of a 10% solution of oxalic acid in water as an electrolyte. With 6 V. the electrolytic etching time ranged from about 3 to 15 sec. However, in some instances a new reagent was found to be necessary. Electrolysis with 5% hydrochloric acid in alcohol was particularly useful in etching alloy 303*C* after it had been tested at 950° and 1000° C.

For nichrome a weaker oxalic acid solution with a potential of about 2 V. clearly defined the grain structure.

Very little success attended the use of the reagents indicated in the literature for etching the chromium irons, but a modification of Vilella's reagent [11] was used for the lower chromium alloys. To Vilella's reagent, consisting of one part of nitric acid, 2 parts of hydrochloric acid and 2 parts of glycerine was added one part of glacial acetic acid. The function of the acetic acid appeared to be the development of the grain boundaries in the alloys and the prevention of staining. With the higher chromium alloy (*A*66*K*) immersion in a 75% solution of hydrochloric acid in ethyl alcohol gave the best results. This is a more concentrated solution than that used by

Kalling and Pagels.* The alloy containing molybdenum was etched electrolytically in a 2½% aqueous oxalic acid solution.

The development of structure in the konel alloys gave the most difficulty. A new reagent consisting of one part of nitric acid, 4 parts of hydrochloric acid, one part of glacial acetic and one part of water gave satisfactory results with alloys 3124 and 2907. Electrolysis was usually necessary to reveal the structures. In the case of the other konel alloys this reagent was modified by the addition of 1½ g. of $CuCl_2(NH_4Cl)_2.2H_2O$ per 100 c.c. of solution. Immersion of the specimen in this solution for about 30 sec. appeared to result in a cleaner etch on subsequent electrolysis, for about 1 sec., to develop the final structure.

Metallography of the Alloys.

Stainless 18/8 *Steels.*

In this group are included four alloys of similar general chemical composition, as well as the stainless alloy containing 0·25% of selenium. Fig. 24 presents a comparison of the microstructures observed in the alloys as fabricated and as normalised from 950° C. Alloys 18/8 and 302*C* exhibit characteristic twinned structures, before and after treatment, of similar grain size. Some twinning was noted in alloy *LE*, but the grain boundaries developed more readily on etching. It is of interest to note the complete absence of twinned structure in alloy *AMK* after normalising. This alloy had considerably more carbon than the other three alloys, and grain boundary precipitation readily defines the structure on etching. This condition is also evident in the structure of the selenium alloy.

In Fig. 25 the structures observed after testing for about 1500 and 900 hr., respectively, at 600° and 700° C. are recorded, while those obtained at 800° and 1000° C. after creep tests are illustrated in Fig. 26. It should be noted that all microsections up to and including the tests at 800° C. are reproduced at 300 diameters. On account of the marked increase in grain size the results of tests at 1000° C. are given at 80 diameters.

Prolonged testing of alloy *LE* at 600° C. results in a precipitation of carbide principally in the grain boundaries, whereas alloy *AMK* shows that precipitation has occurred to about the same extent both in the boundary and also on certain crystallographic planes of the grain. This difference may be associated with the fact that the latter alloy exhibited much greater total plastic deformation during test than did the former. However, *AMK* has a higher carbon content than alloy *LE*. The structural condition of alloy 303*C* is shown in Fig. 25*I*. The appearance of the precipitation at high magnification is markedly different in the three alloys (Figs. 29, *A*, *B* and *D*). Thus the carbides in *LE* were too small for

* *See* Berglund.[12]

resolution under the microscope, whilst those in *AMK* and 303*C* were clearly resolved though markedly different in size.

The alloy with the finest general structure at 600° C. showed the least resistance to deformation (302*C*, Fig. 25*G*). The specimen used for the test (melt *B*) had not received the high-temperature quench after final fabrication. It is of interest to compare the microstructures from the two melts of this alloy. In Figs. 30, *A* and *B*, are given the structures of melts *A* and *B*, respectively, after normalising from 950° C. and annealing for 560 hr. at 600° C. A specimen of melt *B* was also quenched from 1080° C. and then normalised and annealed at 600° C. The resulting grain size (Fig. 30*C*) is comparable with that of the other stainless 18/8 steels.

Some other characteristics of the alloys are shown in Figs. 27 and 28. A complete transverse section of alloy 18/8 (Fig. 28*A*) at 20 diameters shows a marked difference in grain size between the core and the rest of the test section. As fabricated, *LE* exhibits a zone of strained material near the outer surface of the test bar. This zone appears to move inwards as a result of normalising (Figs. 28, *B* and *C*). Despite the heavy work-hardening produced by indentation during testing for Rockwell hardness no recrystallisation is evident in the same alloy after 1500 hr. at 600° C. (Fig. 28*D*), but the profound carbide precipitation should be noted in the region subject to strain. This occurred in an area otherwise apparently free from carbide precipitation (*cf.* Fig. 27*F*). The strain lines found on normalising (Fig. 28*C*) also evidently persist throughout the period of test at 600° C. (Fig. 28*E*). This peripheral structure should be compared with the typical core structure (Fig. 25*A*), and with the typical surface structure of the hot shank (Fig. 27*F*). The development of apparent strain lines on normalising may also be noticed in *AMK* (*cf.* Figs. 28, *F* and *G*).

A comparison between the differences found in the metallographic features of the test section and the hot shank are of interest. Thus, the carbide precipitation in the hot shank of *AMK* was so finely dispersed as to be unresolvable (Figs. 27, *E* and *G*). On account of the heavy cross-section the stress during test was only one-sixth of that applied to the gauge section, where the carbides are readily resolved at 2000 diameters (Fig. 29*B*). The important influence of stress on the resulting microstructure is also evident from a comparison of the hot shank and the test section of alloy 303*C* (*cf.* Figs. 27*H* and 25*I*). This difference persists at 700° and 800° C.

At 700° C. the precipitation of carbides in the grain boundaries is more clearly marked, and the grain structure of alloy 302*C* (melt *A*) is more comparable with that of the other alloys in the series. The surface markings at the edge of the 18/8 alloy appear to have resulted from surface oxidation. Repeated normalising between the load increments may have caused this metallographic difference. An interesting structural condition found in some

of the alloys is illustrated in Figs. 29, *C*, *E* and *F*. Thus, alloy 302*C* exhibits a needle-like phase after etching, which was well defined but difficult to reproduce by photography at 1500 diameters. However, on the hot shank of alloy 18/8 the feather-like needle is clearly shown parallel to and near the top of the micrograph, at low magnification. The appearance of a needle under oblique illumination and at high magnification is illustrated in Fig. 29*F*.

After test at 800° C., the general metallographic features, similar to those observed after test at 700° C., are still evident at 300 diameters. However, the intergranular nature of the fracture, along with evidence of strain, may be noted in the microsection of alloy *LE* (Fig. 28*H*).

Testing at 1000° C. results in such marked coarsening of the grain structure that a magnification of 80 diameters is satisfactory (Fig. 26). Most of the carbide appears to have remained in solution, since there is less evidence of carbide precipitation after 750 hr. at 1000° C. than after the 15-min. normalisation from 950° C. The development of the needle-like structure, however, was much more readily observed. Figs. 29, *G* and *H*, show the general distribution at 80 diameters and the detailed appearance of a needle at 2000 diameters, as observed in the hot shank of alloy *LE*. The nature of this phase has not been determined.

An unetched section of alloy *AMK* (Fig. 30*F*) shows local oxide penetration at the centre of the test bar and near a large intergranular crack. Alloy 302*C* and especially alloy 303*C* were much more prone to oxidation, particularly in the gauge section. Fig. 30*E* is typical of the heavily strained portion of specimen 302*C*. The selenium-bearing alloy (303*C*) oxidised completely through the test section. A heavily oxidised area from this alloy is illustrated in Fig. 30*G*, while Fig. 30*H* is typical of the general microstructure. Even in a "hydrogen" atmosphere marked oxidation occurred (Fig. 30*I*).

A few microstructures of nichrome are reproduced in Figs. 27, *A* to *D*. The pronounced intergranular oxidation under stress at 800° C. is surprising. Apparently this alloy has a high solubility for oxygen, as indicated by the structure obtained (Fig. 27*D*) on submitting the alloy to an atmospheric oxidation test for 400 hr.

Chromium Irons.

A few photomicrographs illustrating the salient features of this series of chromium alloys are presented in Figs. 31, 32 and 33. The first shows the structures of the alloys as received from the manufacturer and after normalising at 950° C. The alloy designated "stainless iron" was similar in chemical composition and microstructure to alloy *A*33*K*. Normalising this alloy resulted in the formation of a martensitic structure.

The carbides in the silchrome and alloy *A*66*K* appear to be undissolved after this 950° C. normalising treatment. Micrographs

of the latter alloy tested at this temperature in hydrogen for 1480 hr. show the formation of a martensitic structure (Figs. 33, *C* and *D*) with only a few carbide particles not in solution.

Since up to ½% of carbide is soluble at 950° C. in a 9% chromium iron, the insolubility in the case of silchrome is probably due to the presence of silicon, which raises the temperature at which the ferrite transforms to austenite.

In the molybdenum-bearing chromium-iron alloy (329*C*) the presence of a new phase is evident. Deeper etching of the normalised sample, to reveal the grain size, dissolved the new phase but did not affect the few carbides remaining after incomplete solution during normalising (Figs. 31, *F* and *G*).

Fig. 32 illustrates the structures of alloys *A*33*K* and *A*66*K* after testing at 600°, 700° and 800° C., at 1000 diameters. In alloy *A*33*K* after 1500 hr. at 600° C. precipitation and spheroidisation are clearly seen. At 700° C. the marked increase in particle size of the carbide in the test section, as compared with the carbide size in the hot shank, where the stress was lower, is noteworthy (Figs. 32, *B* and *C*). Conformation of the effect of stress in speeding up the rate of spheroidisation is found at 800° C. (Figs. 32, *D* and *E*). The evidence relative to this phenomenon is not nearly so clearly revealed in the microstructures of alloy *A*66*K*. Nevertheless, a careful examination of the structures appeared to confirm the observation previously mentioned, pertaining to the effect of stress.

Further support for this deduction is provided by an examination of the structure near the fracture of alloy *A*33*K*, which broke after 345 hr. at 700° C. (Fig. 33*A*). This photomicrograph should be compared with the structures given in Figs. 32, *B* and *C*. The effect of stress and temperature on the size and distribution of the carbide in silchrome is shown in Figs. 33, *H* to *K*. Very little difference could be found between the structures in the test section and in the hot shank at 600° and at 700° C.; however, the profound difference at 800° C. needs no comment.

At the lower temperatures of test, *A*66*K* exhibits a banded structure, which apparently results from carbide segregation. On testing in hydrogen at 950° C. this "duplex" structure becomes more marked. Fig. 33*D* at 1000 diameters shows the microstructure of the centre of the area reproduced at 100 diameters in Fig. 33*C*. The large carbide crystal in the former may be noted in the latter photograph.

A close survey of the results obtained from a study of the test section and hot shank of *A*66*K* at 600°, 700° and 800° C. (Figs. 32, *F* to *K*) will show that stress assisted in the removal of the banded structure.

Figs. 33, *E*, *F* and *G*, show how profoundly 1½% of molybdenum modifies the microstructure of a low-nickel-chromium alloy. Whilst it is known that molybdenum and nickel form an intermetallic compound, there does not appear to be sufficient information

available on the constitution of the alloys to permit of an interpretation of the change in the duplex structure observed as the test temperature is increased.

Incidentally, the structures at 700° and 800° C. appear to be very similar to those presented by Bain and Griffiths[9] for ferrite and austenite (or *B* constituent) in iron-chromium-nickel alloys with more than 24% of chromium when the nickel content is high.

Konel-Type Alloys.

The only published metallographic study of these new alloys relates to the microstructural effect of prolonged heating at 1000° C. in an oxidising atmosphere.[6] The present studies relate to the basic alloy konel and to alloy *K42B* (2948) and its modifications.

In Fig. 34 are reproduced the structures of the alloys as received for test and after normalising for 15 min. at 950° C. All the alloys are of the solid-solution type, but there is a marked difference in grain size in konel after normalising.

In Fig. 35 may be observed the structural reaction of alloys 2948 (*K42B*), 3107 (high cobalt-to-nickel ratio), 2870 (titanium-free) and 2907 (tungsten substituted for chromium) to testing under stress at 600°, 700° and 800° C.

At the lower temperatures, alloy 2948 appears to exhibit little structural change, but at 800° C. a marked increase in the number of the undissolved particles is evident. This phase probably results from carbide spheroidisation, since there is usually between 0·1 and 0·2% of carbon present in the alloy. In specimen 3107 the microstructural characteristics are similar. With the substitution of tungsten for chromium in *K42B*, alloy 2907 shows little change from the normalised structure after testing at 600° and 700° C. There is evidence of rolling cracks at the higher temperature. At 800° C., however, light etching reveals the presence of a precipitated needle-like phase. On etching normally the grain structure developed is similar to that at 700° C. Very little surface penetration due to oxidation could be observed in any of these alloys.

Alloy 2870—*K42B* free from titanium additions—was little different from No. 2948 in the as-received and normalised condition. After testing at 700° C. some intergranular separation may be noted (Fig. 35*I*). Along with the minute carbide spheres a large number of very small inclusions are present. These are probably oxide particles, which are mostly eliminated when titanium is added to the alloy. The alloy has a satisfactory resistance to oxidation.

In the cobalt alloy containing 15% of ferro-titanium (3124) new structural features are recorded, and it should be noted that the photomicrographs were taken at 1000 diameters in contrast to the magnification of 300 used for most of the work. After 1550 hr. at 600° C. under stress, very minute particles of a precipitated phase appear (Fig. 36*A*). At 700° C. this phase is evident in a much larger particle size, while at 800° C. the smaller particle size

present suggests greater solubility than at 700° C. In contrast to the previous observations on the effect of stress in promoting the aggregation of a disperse phase, the reverse condition appears to obtain, for the particle size was greater in the hot shank of this alloy, where the stress was low, after testing at 800° C. than in the highly stressed test section. Possibly high stress increases the solubility of the phase, hence the greater precipitation in the hot shank results in a more rapid coalescence of the disperse phase. This alloy also offered good resistance to oxide penetration. Konel (Figs. 36, *E*, *F* and *G*) exhibits a marked increase in grain size as the test temperature is increased. The grain size near the surface was observed to be consistently much larger than that towards the interior of the test bar. Slight oxide penetration was noticed at 600°, and at 800° C. intergranular oxidation had progressed about half-way towards the centre of the test section.

Alloys 2948 and 3107 appear to be remarkably resistant to grain growth when tested under light load at 1000° C. (Figs. 36, *H* and *I*). The two final structures presented (Figs. 36, *J* and *K*) represent alloy 2907 and konel after testing for 1500 hr. at 950° C. in hydrogen. The grain coarsening of the former is shown at 300 diameters, and the extremely coarse structure developed in konel is evident in the latter structure at 80 diameters.

A comparison of the general structural features of the three types of alloys reveals certain characteristics to which attention should be drawn.

The ferritic chromium alloys, after all the tests conducted, show the presence of carbide particles in greater abundance and larger size than those found in the austenitic stainless steels. Furthermore, the weak ferritic type of alloys exhibits a much smaller grain size. This is not so apparent from the photomicrographs, since those of the chromium alloys are reproduced at 1000 diameters, whereas those of the austenitic steels were taken at a magnification of 300.

The markedly smaller grains of the *K*42*B*-type alloys as compared with the 18/8 steels is clearly shown, but any precipitated phase produced in the former alloys during prolonged heating at any test temperature does not become sufficiently large to be resolved under the microscope. The alloys retain their apparently homogeneous character of phase. This fact is in contrast to the behaviour of the carbide particles in stainless steels. The precipitation and aggregation of these carbides have been much studied and the phenomenon has been specifically discussed in the present paper. In view of the observed difference between the two classes of alloys, it is of interest to note that as the test temperature is increased, the superior resistance to deformation of the konel-type alloys becomes increasingly marked.

At the highest test temperatures the konel alloys, although susceptible to corrosion and oxide penetration, have better resistance to oxidation under stress than either of the other two groups

of alloys. No doubt this resistance, to some extent, accounts for their greater high-temperature strength as compared to the stainless steels.

A general correlation of the tabulated data and microstructures provides information on the high-temperature ductility of the alloys. Thus the ferritic chromium alloys, with the exception of *A66K* at 800°, possess good ductility as indicated by the total elongation without fracture, whereas the 18/8 steels and konel alloys have only fair ductility. Since few of the alloys were strained to fracture, recourse must be had to visual examination under the microscope, in order to ascertain whether the small amounts of elongation were accompanied by any brittle characteristics. No evidence of lack of ductility was noted in the stainless steels below 800° C., but two samples of *LE* fractured under load at this temperature with 1% and 2% elongation, and a sample of 18/8 fractured at the same temperature with 6% elongation. The konel-type alloys gave only one fracture—konel at 800° C. with 7½% elongation. Alloy 2870 exhibited intergranular separation at 700° C. with 6% elongation, and at 800° C. with 4% elongation. Alloy 2907 also gave similar evidence after 1480 hr. of test at 950° C. in hydrogen with less than 2% elongation. Indications of brittleness were absent from the microstructures of the other alloys in this series. However, the maximum deformation was only about 4%.

Magnetic Tests.

It was noticed that after test some of the stainless 18/8 steels were attracted fairly strongly by a magnet. In certain instances, where the alloys had oxidised sufficiently to form an appreciable surface scale, the magnetic attraction was very strong. Removal of the scale, however, usually showed the alloy to be weakly magnetic.

It was considered of interest to conduct a simple test for the magnetic quality of all the stainless-steel rods which had been subjected to the time-stress tests at constant temperature. The rod was suspended and an observation made on the distance through which the free end could be displaced by a strong horse-shoe magnet. The purely qualitative but comparative results are given in Table V.

The persistence of magnetism in alloy *LE* may be noted. This alloy has the lowest nickel plus chromium content. However, alloy 18/8, which exhibited moderately strong magnetic attraction after test at 700° C., has the highest nickel plus chromium content, although the carbon content is the lowest in the series. Susceptibility to magnetisation has been used as a means of following a tendency of 18/8 steels to corrode, and Krivobok[13] has presented data which invariably show that the more magnetic the alloy the greater is the tendency towards intergranular corrosion. In the present work it appears that the more magnetic the alloy becomes

during test, the shorter is the life of the alloy under strain before failure occurs. Thus alloys *LE* and 18/8 both failed in a relatively short time under test.

TABLE V.—*Magnetic Characteristics of the Test Bars of the Stainless 18/8 Steels as Revealed by their Attraction to a Permanent Magnet.*

Alloy Designation.	As-Received.	Normalised from 950°C.	After Creep Test at—				
			600° C.	700° C.	800° C.	950° C	1000° C.
LE . .	M	VW	MS	S	M	...	VW
AMK .	N	N	N-VW	N	N	...	VW
18/8 . .	N	N-VW	N-VW	M	W	...	...
302*C-A* .	N	VW-W	...	VW-W	VW-W	...	...
302*C-B* .	MS	VW	N-VW	...	...	...	N-VW
303*C-A* .	N	N	N-VW	N-VW	VW	...	...
303*C-B* .	N	N	N-VW	...	...	N	VW

N = No apparent magnetic attraction. M = Magnetic.
VW = Very slightly magnetic. MS = Moderately strongly magnetic.
W = Slightly magnetic. S = Strongly magnetic.

The above terms are necessarily only relative. The scale formed in the 950° and 1000° C. tests was strongly magnetic. At lower temperatures very little scaling was observed.

In the as-received condition, alloy 302*C*, melt *B*, was the only material which exhibited any perceptible magnetism. It was mentioned in the discussion of the metallography of the alloys that the high-temperature quench had been omitted in the preparation of this alloy.

General Discussion.

The new method described for the study of alloys at elevated temperatures permits of a rapid survey of the tensile deformation characteristics of alloys, and provides data which are strictly comparable.

The difference in the behaviour of the 18/8 stainless steels is more marked than was anticipated. Thus at 700° C. and a load of 8000 lb. per sq. in. the percentage creep rate per 1000 hr. ranges from 0·9 to 2·9 after a total of about 900 hr. at test temperature. At 600° C. the range is nil to 0·4%, although the majority of the tests suggest a value of 0·03%. It is interesting to compare these values with those recently published by Cross and Lowther[14] in their most accurate creep tests at 650° C. under a stress of 8345 lb. per sq. in. At 1000 hr. they give 0·23 and 0·18% per 1000 hr. for two stainless 18/8 alloy samples. The total elongation at 1600 hr. is recorded as 0·67% and 0·50%, respectively. In the present research the figures obtained for the total plastic elongation at 600°C. ranged from 0·04 to 0·6% in 1500 hr., and at 700° C. from 0·4 to

1·1% for 900 hr. They are calculated from the difference between the total elongation and the elastic recovery for the load considered.

It was hoped that a careful study of the microstructures would throw more light on the reasons for the difference in the high-temperature resistance to deformation of the alloys. In general the as-received and the normalised structures were taken from a transverse section and the stressed structures from a longitudinal section. However, there was usually little difference between transverse and longitudinal sections, with the exception of the selenium-bearing alloy. The presence of selenium appears to result in grain refinement and an alloy having the maximum creep resistance at the lower temperatures of test. Furthermore, the contraction resulting from a structural change, probably a precipitation, further enhances the apparently smaller creep rate noted in this alloy.

Considering first the stainless 18/8 steels at 600° C., it was found that the alloy in which the precipitation and aggregation of carbide particles was easily resolvable at 1800 diameters (*AMK*, Fig. 29*B*) had approximately the same creep resistance as the alloy exhibiting unresolved carbide particles (*LE*, Fig. 29*A*). The presence of relatively large carbides in *AMK* is probably due to this alloy containing the most carbon and hence a greater precipitation resulting in more rapid coalescence. The greater difference in cross-sectional area between the gauge section and the shank of alloy *AMK* permits of the observation of the effect produced on the microstructure by a more marked variation in strain. Thus the greater strain in the test section at 600° C. probably accounts for the larger and more clearly defined carbide particles as compared with those in the hot shank (*cf.* Figs. 25*C* and 27*E*). Despite the smaller strain difference in the shank and the gauge section of alloy 303*C*, the heavier section is free from the twinning found in the test section at 600°, 700° and 800° C. Furthermore, the observed carbide precipitation dispersed throughout the more heavily strained structure (Fig. 25*I*) is absent from the hot shank (Fig. 27*H*).

Whilst the appearance of the needle-like structure seems to indicate the development of a new phase, no correlation with the properties has so far been possible. Evidence of this structure has been found in nearly all the stressed specimens, but it is difficult to photograph. Sometimes the needles may be observed in the hot shank alone and at other times in the gauge length. Thus, in alloy *LE*, on testing at 1000° C. the needle-like structure illustrated in Figs. 29, *G* and *H*, was found only in the hot shank.

The apparent susceptibility of nichrome to oxidation at 800° C. under stress is surprising. It is probably due to the large amount of plastic deformation resulting from a stress of 4000 lb. per sq. in. Tested at 950° C. in hydrogen, there is a complete absence of intergranular cracking.

The behaviour of the two stainless irons (12% chromium) under

stress is not very different, and the resulting microstructures are identical. The higher the test temperature the more spheroidised do the carbide particles become, and the greater strain in the gauge section appears to promote diffusion and aggregation as compared with the smaller stress in the hot shank. This is at variance with the conclusions of Mooradian and Norton.[15]

Again, a study of the metallography of the 18% straight chromium alloy (*A66K*) indicates the speeding-up of the carbide aggregation by the greater stress in the gauge section. However, the increase in the rate of spheroidisation resulting from high stress is most clearly shown in silchrome, particularly in the tests at 800° C., where the alloy offers a very low resistance to creep even under a stress of 2000 lb. per sq. in.

The 24% chromium alloy with both nickel and molybdenum additions is the strongest of this ferritic group. Despite the well-known effect of molybdenum, it is uncertain in the present instance how much effect can be ascribed to possible contraction resulting from the profound structural change occurring during test and how much to inherent resistance to creep.

The microstructural features of alloy *K42B* and its modifications are really very similar, although alloys *K42B* (2948) and 3107 (high cobalt-to-nickel ratio) are outstanding in their high-temperature tensile properties. Evidently the omission of titanium (2870) results in a marked decrease in resistance to deformation, but the cause is not evident in the microstructure. Whilst it has been demonstrated in previously published work that the remarkable high-temperature strength of the konel alloys arises from precipitation-hardening, no definite evidence of a disperse phase has been found under the microscope. Apparently temperatures sufficiently high to cause marked aggregation of the phase result in the re-solution of the precipitate.

The substitution of tungsten for chromium (2907) causes a decrease in strength which is particularly noticeable at 800° C. Konel, in which there was a marked increase in the grain size with the test temperature, would probably have exhibited deformation characteristics more similar to those of some of the stronger alloys had it not been softened repeatedly by normalising before each load increment. However, its remarkable strength, possibly associated with a coarse grain, shown during the test in hydrogen at 950° C. for 1600 hr., was not to be anticipated. Alloy 3124, although exhibiting a marked phase change at the test temperatures, possessed a relatively low creep resistance.

In the deformation tests at 800° C., nichrome fractured after 840 hr. under 4000 lb. per sq. in., and the high ductility of the stainless-iron and silchrome alloys was very evident when compared with the small elongation of some of the other materials.

Good resistance to oxidation was exhibited by all the alloys with the exception of the sample of stainless iron. However, tests on

alloy *A33K*, of similar chemical composition, did not reveal the surface characteristics observed on the stainless iron. The smooth surface on silchrome was particularly striking.

The large number of time-deformation curves presented in Part I. renders it a little difficult to obtain a clear perspective of the relative

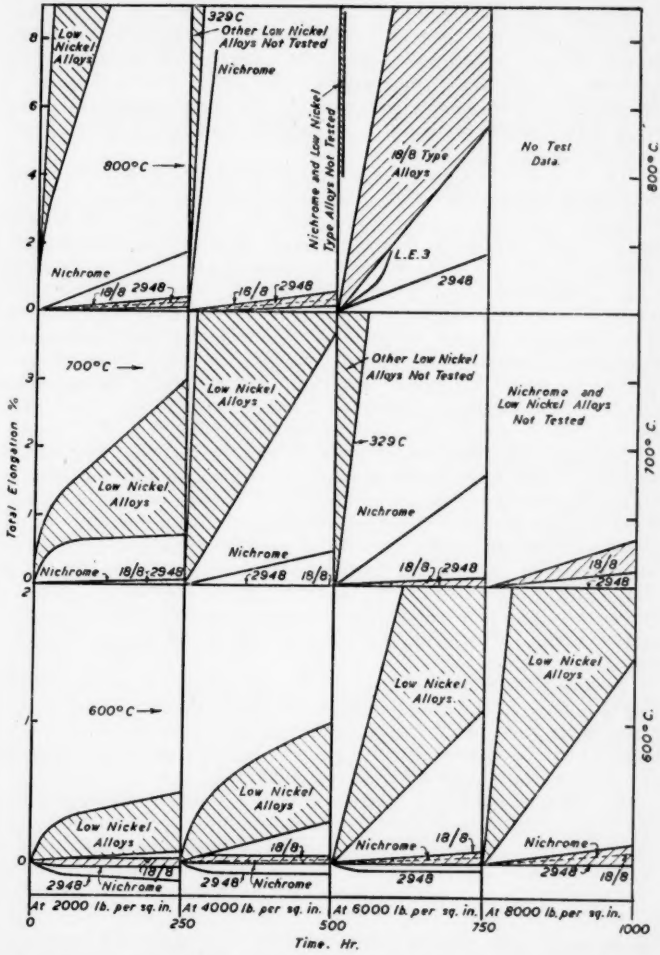

FIG. 37.—Comparison Data on Alloys Tested at 600°, 700° and 800° C.

merits of the three classes of alloys tested. However, it is believed that a concise general picture of all the information on creep resistance is obtained from a study of the composite diagram shown in Fig. 37. After each movement under load at constant temperature it was necessary to trace the time-deformation characteristics from the origin, in order to have a common starting point from which to indicate the subsequent spread of the data for each of the three series of alloys. A time of 250 hr. was arbitrarily selected as the period of test. Naturally, the wide variation in chemical composition of the konel-type alloys resulted in very considerable divergence of behaviour; accordingly, the creep characteristics of alloy *K42B* (2948) were taken as indicative of the optimum high-temperature strength of this series.

Thus, in this diagrammatic picture the authors have depicted the spread and location of the time-deformation relation of stainless 18/8 steels and ferritic chromium alloys at 600°, 700° and 800° C. under stresses of 2000, 4000, 6000 and 8000 lb. per sq. in. The position for the line indicating the properties of the well-known high-temperature alloy nichrome, as well as that for *K42B*, have been included as a basis for comparison. It is important to note that there is a change in scale of the ordinate (total percentage elongation); actually the temperature effect is much greater than is at once apparent. A similar comment also applies to the apparent rates of deformation as indicated by the slopes of the strain-time curves.

It should not be necessary to emphasise the fact that the authors present this diagram merely in an effort to illustrate the comparative high-temperature properties of the alloys. Undoubtedly the striking feature is the profound difference observed in the behaviours of the ferritic chromium alloys and the austenitic stainless 18/8 steels. At each of the three temperatures the behaviour of the konel-type alloy (*K42B*) is comparable to that of stainless steel at low stresses, but as the stress is increased the superior strength of *K42B* becomes more evident. This is particularly more noticeable as the temperature is increased.

Despite the variations in chemical composition among the ferritic chromium alloys, the spread in the test data of this group of materials would have been much less than that indicated by the shaded segments but for the relatively greater high-temperature strength of the alloy containing 1·6% of molybdenum.

In order to present a relative idea of the effect of temperature on the deformation rates of the groups of alloys and to indicate the difference in high-temperature strength between the three groups, a diagram has been prepared on semi-logarithmic co-ordinates, plotting the stress in pounds per square inch against the logarithm of the rate of deformation (Fig. 38). Since there was considerable scatter in the deformation rates between the various alloys in any one group, a shaded band was selected which included practically

all of the data obtained in the present investigation for stainless 18/8 steels and for the chromium irons.

It may be noted that boundary lines enclosing the shaded areas have been omitted. Like the previous diagram, Fig. 38 is intended simply to illustrate the comparative deformation rates of the alloy classes and their general distribution with respect to creep rate and

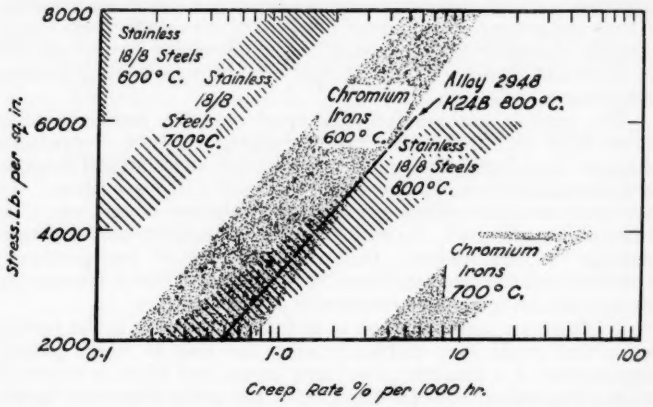

FIG. 38.—Comparative Effects of Temperature on the Approximate Distribution of the Stress-Deformation Relationship for Stainless Steels and Chromium Irons.

stress. Of the konel-type alloys the relation between the deformation rate and stress for alloy 2948 (*K42B*) at 800° C. alone was included.

With the above comments in mind it is suggested that Fig. 38 presents a useful picture of the order of magnitude of the creep-rate/stress relationships that may be anticipated in the types of alloys investigated within the temperature and stress limits studied.

It is not proposed to theorise here on the reasons for the difference in behaviour of the groups of alloys nor on the scatter obtained with the several " similar " specimens of stainless 18/8 steel, since the information obtained at this time does not appear to warrant such conclusions.

It is gratifying to find that engineers are striving to interpret the significance of creep data and to separate the factors which may be influencing the results. Weaver [16] attempts to separate creep phenomena into two distinct phases—the initial plastic stage in which strain-hardening occurs, and the viscous flow where the rate of strain is constant. However, despite the interesting mathematical analysis which correlates his long-time creep data, it is difficult to

understand the meaning of the term " viscous flow " in relation to a crystalline aggregate.

In a recent paper, Soderberg[17] reverses his earlier thesis that strain-hardening plays an important rôle in influencing creep, for he concludes that since the curvature of creep curves for low stresses is just as decided as that for high stress, strain-hardening is ruled out as an important factor. It is then pointed out that materials undergo structural changes under the combined influence of time and temperature, and one is led to believe that these structural changes constitute the important factor influencing creep, and that up to certain limiting values the structural changes are independent of the stress and strain.

The present authors feel that there is little justification for these most recent observations, particularly if by " structural changes " is inferred the commonly accepted metallurgical meaning of a change in the amount or distribution of a disperse phase. Do not pure metals exhibit geometrically similar creep curves at different low stresses? In such cases, the possibility of " structural changes " is not evident. One of the authors[18] has previously demonstrated the profound effect of minute amounts of deformation on the time/creep-rate characteristics of pure metals.

Furthermore, there appears to be definite evidence in the present work that strain may markedly affect the rate at which particle aggregation of a disperse phase may occur, and there is reason to believe that submicroscopic changes are the really important factors which, although elusive, yet presumably serve to modify profoundly the creep characteristics of " similar " alloys.

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CORRESPONDENCE.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield) wrote that the paper covered ground which deserved and was receiving much attention at the present time, and the authors were to be congratulated on having presented some most valuable data.

The new apparatus described was very ingenious and had the advantage of permitting a number of tests to be carried out in the same furnace and hence with the same thermal history and temperature control. One might perhaps criticise the small dimensions of test-piece which this involved, but obviously one could not have every advantage in one apparatus.

With regard to the materials tested, the high-chromium (ferritic) and 18/8 types were, of course, well known, but the alloys containing cobalt were not so well known, although a number of such alloys were now receiving attention by various experimenters. One feature militating against the greater use of this element was its high cost, but, as seen in certain other fields of application, this was not necessarily a hindrance to its use.

With regard to the results, the variability in the behaviour of the various 18/8 alloys at low temperature, whilst not altogether surprising, was somewhat greater than one would expect. The conditions of fabrication were probably important factors on this question, but, as had been shown in other directions, "abnormality" could exist even in plain carbon steels and the cause was not yet understood.

The relative behaviour of the austenitic and ferritic steels was in line with other work. The influence of cobalt and titanium, respectively, together and separately, were not yet clear, but it was obvious that as regards strength at high temperatures both these elements offered possibilities. The contraction under load at temperature indicated some degree of instability, and one would prefer that materials for use at high temperatures should be stable. Possibly this might be brought about by some initial thermal treatment, but naturally, provided that the order of such contraction was not great, it was not serious and it might even be considered to be an advantage as partly offsetting the "creep" extension and normal thermal expansion.

One appreciated the efforts of the authors to simplify the presentation of the results by the diagrams in Figs. 37 and 38, but such diagrams must clearly be regarded in a very tentative manner. Also, the use of the same specimen for creep tests under different stresses, even at the same temperature, was not generally to be recommended, as the data tended to be confused thereby.

The authors' microscopic studies of the changes of structure were of great interest and they were to be congratulated on the photographs and the Iron and Steel Institute on their reproductions. Carbide precipitation effects were well brought out, as also the

formation of " twins," needles and in certain cases intercrystalline separation. It was unfortunate that no closer connection between these structures and the creep data had been found.

There were two requests one would like to make to the authors, namely, for more complete analyses of the nichrome and of the cobalt alloys—*e.g.*, the carbon contents—and for an indication of the hot-working conditions employed for all the materials referred to.

Professor Dr.-Ing. E. H. SCHULZ and Dr.-Ing. H. SCHOLZ (Dortmund, Germany) wrote that simplifications in testing apparatus and methods were naturally to be welcomed on principle. In this respect, however, particular care seemed still to be required in the case of creep-test methods, because the scatter in the results obtained at different testing laboratories demanded in the first place the exclusion or diminution of the sources of error, which obviously were not yet completely understood. Thus, referring to the results of American co-operative experiments published by C. L. Clark,[1] the extent of the scatter obtained at the individual testing stations must be considered to be still extraordinarily great. The co-operative experiments carried out at different places also contained much scattering.

Concerning the experimental apparatus described by the authors, the following was to be said :

(1) Instead of the previously generally-used weight loading, spring loading was provided. Objections might be raised against that, because experiments with decreasing stress had shown that difficultly controllable relations between the degree of stiffness of a spring loading device and the course of the extension of the test bar could arise, the influence of which on the experimental results could be determined or even excluded only with difficulty.

(2) At the Research Institute of the Vereinigte Stahlwerke A.-G., Dortmund, heat-equalising bodies, made of metals of high thermal conductivity (high-copper alloys or silver), were arranged on the test bars in creep tests. These heat-equalising bodies enclosed the specimen about its gauge-length so closely that, although the extension process was not interfered with, a practically completely uniform temperature was attained along the gauge-length. The use of such heat-equalising bodies was to be strongly recommended. By this means the temperature within the gauge-length was raised in such a way that, without any reduction of the cross-section of the bar, the extension of the gauge-length could be accurately measured outside the furnace by the movement of the grips. Without such a heat-equalising body the temperature of the specimen, measured from the grip to its mid-point, differed at all points, even though a furnace very much longer than the gauge-length was used.

[1] *Transactions of the American Society of Mechanical Engineers*, 1937, vol. 59, RP–59–4, pp. 439–440.

(3) Elsewhere attempts had been made to restrict the extension to the gauge-length by reducing very much the cross-section within the gauge-length in comparison with that of the rest of the bar. At the transition from the thinner to the thicker part such a great restriction on the process of flow was set up, however, that usually the values measured were too low.

In regard to the authors' experiments the writers would remark in conclusion that, according to investigations made in the Research Institute of the Vereinigte Stahlwerke A.-G., a practical creep limit no longer existed in a steel when it was stressed in the recrystallisation-temperature range. As this temperature for chromium steels should certainly lie below 600° C., tests extending to 1200 hr. gave no indication of the actual behaviour of these steels in more prolonged service.

AUTHORS' REPLY.

The AUTHORS, in reply, wrote that they were pleased to have the comments from Dr. Hatfield, who had contributed so extensively to our knowledge of high-temperature metallic materials. It was helpful to have emphasised the fact that the diagrams presented in Figs. 37 and 38, summarising the general time-deformation and creep characteristics, respectively, of the alloys, must be regarded in a tentative manner.

While some authorities were no doubt aware of the fact that the austenitic alloys were stronger than the ferritic materials, the authors believed that the present research represented the first occasion where a quantitative picture of the remarkable differences in the strength at high temperatures had been recorded.

The authors regretted that they did not have available at this time the data on the analysis and hot-working conditions requested by Dr. Hatfield, but tests were in hand which, it was hoped, would provide information on the effect of preheat-treatment on the creep of samples of hot-rolled 18/8 stainless steel taken from the same bar, and kindly provided by Dr. V. N. Krivobok of the Allegheny Steel Company.

The comments of Dr. Schulz and Mr. Scholz were appreciated. While it was admitted that spring loading might have unsatisfactory features, the relaxation resulting from creep in most of the experimental data was so small as to be unimportant. However, one of the authors (Professor Austin) had recently developed a modification of the equipment described in the paper, whereby dead loading was substituted for the spring tension. It was hoped to describe this equipment in detail in the near future.

The introduction of heat-equalising bodies around the gauge section was unquestionably a step in the right direction, and the comment on the relation of the recrystallisation temperature to a

practical creep limit was of much interest. Some investigators had attempted to correlate the creep behaviour and the equi-cohesive temperature, which had also been considered to approximate to the temperature of crystallisation. The authors, however, considered that these terms must have a more specific meaning before any weight could be given to a proposed correlation. This was particularly true of recrystallisation, a phenomenon which depended profoundly on the magnitude of the stressing operation. One well-known example would suffice. In heavily drawn copper, softening or recrystallisation might occur on annealing below 200° C.; with lightly cold-worked copper softening or recrystallisation could not be effected until a temperature of about 600° C. was reached.

INFLUENCE OF COMPOSITION AND TREATMENT ON THE RATE OF ACID ATTACK ON MILD STEEL.[1]

By Principal C. A. EDWARDS, D.Sc., F.R.S., D. LUTHER PHILLIPS, M.Sc., and D. F. G. THOMAS, B.Sc. (Swansea).

(Fig. 1 = Plate XXII.)

Summary.

This investigation deals with the influence of phosphorus, carbon, sulphur and copper on the rate of attack by 6% sulphuric and 2% citric acids on mild steels, both in the annealed and in the heavily cold-rolled conditions.

The steels were made in quantities of about 24 lb. in a high-frequency induction furnace under carefully controlled conditions, and chill-cast in the form of thick plates suitable for rolling into packs of thin sheets, as in ordinary tinplate practice.

From time to time a large number of publications have appeared dealing with different aspects of the influence of various elements on the corrodibility and rate of solution of steel. Many of these, however, have little direct bearing on the work described in the present paper. So far as the authors are aware, the more important researches that have much relation to their own work are those of Stead,[2] of Morris and Bryan,[3] of Hoar and Havenhand,[4] and of J. A. Jones.[5]

Those interested will find a very valuable bibliography on the influence of copper on the corrosion resistance of iron and steel in the First Report of the Corrosion Committee.[6]

In the present investigation, the object has been to make a careful study of the influence of phosphorus, carbon, sulphur and copper upon the rate at which steel will dissolve when immersed in two different acid solutions. The two solutions which have been used for this purpose were (*a*) one containing 6% of sulphuric acid in water, and (*b*) another containing 2% of citric acid in water.

At the outset, it was recognised that the value of the results

[1] Received January 24, 1938.

[2] J. E. Stead, *Journal of the Iron and Steel Institute*, 1916, No. II., p. 5.

[3] T. M. Morris and J. M. Bryan, *Report of the Food Investigation Board*, 1933.

[4] T. P. Hoar and D. Havenhand, *Journal of the Iron and Steel Institute*, 1936, No. I., p. 239P.

[5] J. A. Jones, *Journal of the Iron and Steel Institute*, 1937, No. I., p. 113P.

[6] *Iron and Steel Institute*, 1931, *Special Report No.* 1.

obtained might be seriously affected by the care taken in selecting the experimental samples. In this connection, the authors were more especially concerned with (*a*) the question of the regularity of composition, or the avoidance of unnecessary segregation of the different elements in the finished sheets, and (*b*) the standardisation or careful control of the heat treatment of the various rolling operations during the production of the sheets. In many respects, the first of these was thought to be the more important; at the same time, it was anticipated that the method whereby it was hoped to minimise the degree of segregation would prove to be a means of reducing the extent of the variations which might be introduced during the many operations of heating and rolling. The disturbing effects of an irregularity of composition which arise during the comparatively slow cooling of the large ingots can be very disconcerting when dealing with problems such as the corrosion of steel by immersion of small samples in acid solutions. In this connection the possibility of serious experimental errors is especially marked with samples cut from such thin sheets as are used in tinplate making.

Under normal commercial conditions, segregation cannot be entirely overcome, and this might give rise to wide differences in the distribution of certain elements in different parts of the same sheet. As far as possible, the authors were anxious to eliminate uncertainties which might arise from irregularities of this kind. With this in view, efforts were made to develop a method of casting small quantities of steel into the usual form of bar suitable for rolling into tinplate. In other words, the aim was to make cast bars which were similar in size and shape to those which are now rolled from ingots for the ordinary tinplate mills. By proceeding in this way it was expected that the rate of solidification would be so rapid that the degree of segregation would be reduced to a minimum. If this could be accomplished, the authors felt reasonably sure of obtaining sheets in which there would be extremely little, if any, variation in the chemical composition of any part of the sheets made from a given bar; further, it was anticipated that, by proceeding in this way, more reliable results would be obtained, because some of the normal commercial operations of heating, rolling, &c. (*i.e.*, those between the casting of the ingot and the production of tinplate bars), would be eliminated. Still another advantage, in the direction of convenience and cost, would be that the quantity of each cast of special composition would be more in accord with the amount actually required. If special charges were made in ordinary commercial furnaces, much larger quantities would have to be made; and, since the chemical compositions of many of the samples required for the experiments were such as to render the material useless for ordinary tinplate making, it would give rise to a considerable amount of undesirable waste. At this stage, it should be mentioned that the authors wished to avoid being forced to

adopt the method of trying to make one special ingot from an ordinary charge by the addition of elements to the steel while casting from the ladle to the ingot mould was in progress.

Melting and Casting the Charges.

The procedure for melting and the general preparation of the charge prior to casting was in broad outline much the same as that already described in the work which had been carried out for the Committee on the Heterogeneity of Steel Ingots. Briefly, they were as follows: The melts were made in a 15-kW. Ajax-Northrup furnace under carefully standardised conditions. The main part of the charge usually consisted of Armco bars, and sometimes of lumps of Swedish Lancashire iron, but, in the form as received, the desired quantity could not be added in one lot. The pot was, therefore, charged as full as possible, and the remainder preheated in a gas furnace. When the first part of the charge had melted, the slag was thickened with sand and removed with rods. More charge was then added and the procedure repeated, by which time the whole charge of 25 lb. was in the crucible. The metal was all molten in approximately 1 hr. 20 min., and after 5 min. superheating, the slag was thickened and removed ready for the additions. Twenty grammes of manganese were then added, or its equivalent in ferro-manganese, depending on the final carbon figure desired. After covering the molten metal with sand, the sheathed tungsten-molybdenum couple was inserted, and by varying the furnace load, the metal was, in a minute or two, brought to a temperature of 1600° C. The slag was removed, the remainder of the manganese added, and any other appropriate additions, such as phosphide of iron, sulphide of iron or copper, were then made. Finally, the deoxidising addition of ferro-silicon was made, the last traces of slag were removed, and the metal was poured. The whole operation took approximately 1½ hr.

With regard to the methods of casting that were tried in the early stages of the work, it is unnecessary to give a detailed description of the various unsuccessful attempts. Numerous kinds of sand moulds were tried, and many different classes of mould dressings were also used. It was found, however, that none of the products so obtained could be rolled into good sheets. The chief difficulty in this connection was due to a layer of sand being tenaciously fused on to, if not, indeed, into the surface of the casting. Many attempts were made to remove this semi-fused layer of sand, either by pickling in a strong solution of sulphuric acid, by sandblasting, or by scaling the surfaces by oxidation, &c., but none was completely successful. The rolled sheets were found to have defective surfaces, which took the form of a badly scratched or scored appearance. No doubt, this was primarily due to particles of sand having been enclosed between the sheets after doubling for rolling.

It was finally decided to use cast-iron moulds, and a sketch and

photograph of one of these are shown in Fig. 1. The first cast-iron moulds were designed to give a casting of exactly the right dimensions required for rolling into sheets, without having to resort to any preliminary machining. It was found, however, that the stream of liquid metal tended to impinge upon the side surfaces of the mould as it ran from the tundish. This caused the surfaces to be rather quickly worn away locally, with the production of a corresponding roughness on the cast bar. To prevent this wearing action, the design of the mould was modified in such a way that the thickness of the middle of the casting was increased, thus permitting the liquid metal to fall into the mould without striking the sides. This extra thickness had to be removed by machining before rolling the bars into sheets. It should also be mentioned that it was necessary to cut off a thin slice of about $\frac{1}{4}$ in. from the upper edge of the casting, in order to obtain what may be described as a normal shape in this part of the bar. When this was done, in a few isolated instances indications of a small pipe cavity could be seen, but this gave no trouble, as care was taken to note the position of this defect in relation to the finished sheets, and no samples were used from that particular portion.

Brief Description of the Hot-Rolling Procedure.

The bars were heated in a reheating furnace at a tinplate works to a temperature of about 750° C. They were given four passes in a two-high roughing mill in the direction of the width of the original bar. The resulting "singles" were reheated and, by means of two passes in a two-high finishing mill, were rolled to almost twice their length. Each long single sheet, while still hot, was folded back on itself, to give two sheets known as "doubles," which were again heated and rolled to twice their length as doubles. The long doubles were folded back on themselves as in the previous operation, to produce four sheets called "fours." The pack of fours was reheated, and rolled to a length calculated from the weight of the original bar which would give sheets of a finished thickness of 0·6 mm., or 0·024 in.

Preparation of Samples for Cold-Attack Experiments.

Small samples were cut from the hot-rolled sheets, and after annealing and pickling, &c., they were cold-rolled in a small hand-operated mill with highly polished rolls to half the original thickness (*i.e.*, corresponding to an elongation in the cold-rolling of about 100%). In other words, all the samples were cold-rolled to the same extent, and thus the smoothness and general character of the surfaces of all specimens were standardised. Some of these samples were then tested for the rate of acid attack in the cold-rolled condition after they had been carefully cleaned from oil or grease by

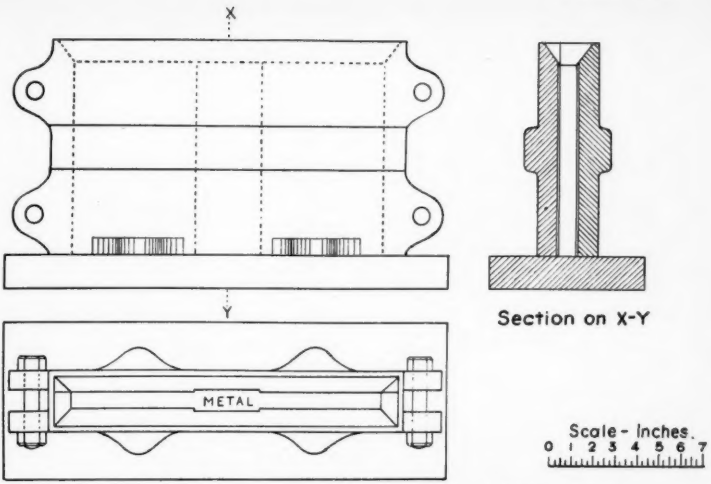

FIG. 1A (*see* FIG. 1B).—The Mould in which the Experimental Melts were Cast.

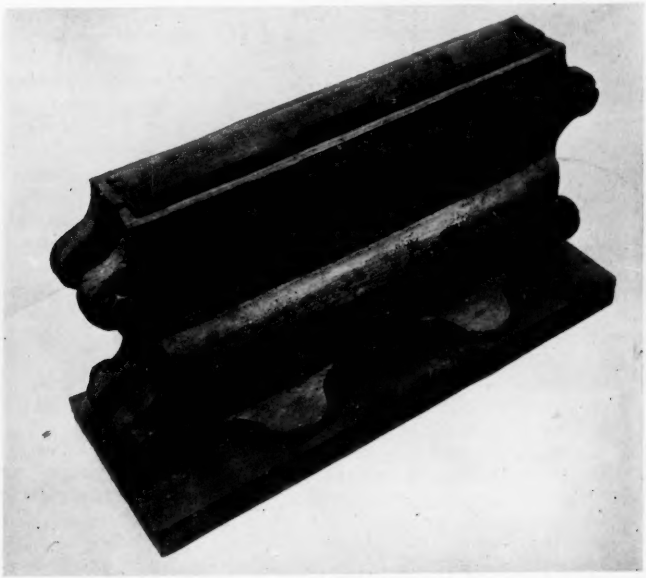

FIG. 1B (*see* FIG. 1A).—The Mould in which the Experimental Melts were Cast.

[*Edwards, Phillips and Thomas.*

[*To face p.* 226 P.

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means of acetone, whilst others were first annealed at 950° C. for 1 hr., followed by relatively slow cooling, before testing.

Some Early Experimental Difficulties.

In the early experiments for the determination of the rate of acid attack, the volumes of hydrogen evolved at definite intervals of time were measured; but after some experience of this procedure it was decided to adopt the method of direct weighing after immersion for the required times. For this purpose, the specimens were quickly removed from the acid solutions and carefully washed and dried.

Effects of Comparatively Small Changes in the Method of Annealing upon the Results Obtained.

During the early stages of the work some disconcerting irregularities in the results obtained were observed. It appeared to be quite impossible to get anything like reasonable agreement between three specimens cut from adjacent positions in a sheet and annealed at the same time. The extent of this disagreement was much greater than could be associated with normal experimental error, and for a long time the position was very discouraging. In some respects, however, the wide differences observed could be regarded with a certain amount of satisfaction, because they indicated that the disturbing factor was so glaringly evident in its effects. This stimulated a keener interest in attempting to locate it; and, further, it was felt that, once the cause of the trouble was eliminated, clearer indications would be given by the improvements in the results than if the original differences had been small.

Without discussing in detail the many trials that were made and the failures experienced in endeavouring to obtain concordant results, it is of interest, and possible significance, to give a brief account of the main features of the difficulties and how they were finally overcome.

In the first place, it should be mentioned that it was considered desirable to make three corrosion tests for each condition in which an experimental sample sheet was examined. It should be mentioned that in all cases the dimensions of the test samples were 5 cm. by 2 cm. by 0·31 mm. thick. In order to prevent oxidation during annealing, three of these samples were carefully and compactly wrapped up in the thinnest commercial black sheets procurable. These special sheets, known in the trade as "tagger" sheets, were 0·15 mm. thick. The samples in each packet of this kind had about six layers of wrapping about them. These packets were placed in a small electric furnace which was already at a temperature of 950° C. and left there for an hour, after which they were withdrawn and cooled by placing them in a small iron box filled with town gas. After this treatment the samples were always

perfectly bright and free from even traces of oxide films, and, so far as could be observed, all three samples from a given packet appeared to be identical.

Each sample was bent to enable it to stand on its edges, and was then placed in a separate flask to which was added 250 c.c. of a solution of 6% sulphuric acid in water. The temperature was kept constant by immersing the flasks in a large water-bath under thermostatic control. At definite intervals of time the samples were withdrawn, washed, dried and weighed.

It was noticed that two of the test samples gave much higher values for the rates of acid attack than the third, and, further, it was observed that one surface of each of these two specimens had been more rapidly attacked than the other. When these facts had been definitely established, it was observed that the two surfaces showing the greater degree of attack were those which had been in contact with the material used for wrapping up the bundle. Whilst still not knowing the real cause for the anomalies, it was thought that the difficulties could be satisfactorily met by packing five specimens together in the parcel for annealing, and discarding the two outside ones; when this was done, it was found that closely agreeing results were obtained from the remaining three. A typical set of results is as follows:

Five Specimens Wrapped in Tagger Wrapping.

		No. 1. Outside.	No. 2. Inside.	No. 3. Inside.	No. 4. Inside.	No. 5. Outside.
Loss of weight.	G.	0·2552	0·1710	0·1572	0·1715	0·2448

The authors felt confident that no serious errors would have arisen by continuing in this way, but it would have left some feelings of uncertainty. For example, if the material used as the wrapping was the cause of the trouble, it would affect the edges of the three inside specimens and, possibly, their surfaces to a lesser degree. It was therefore decided to proceed with the annealing of all samples in the following manner: Carefully roll a small portion of one of the sheets from each cast to a thin gauge, and use some of this as a first protective wrapping for each bundle of samples for annealing, along with a further good outer wrapping of ordinary tagger sheets. By doing this very good agreement between the individual results from the five different samples of the same sheets was obtained; this is illustrated in the following:

Five Specimens Wrapped in Thin Sheets of Same Material.

		No. 1. Outside.	No. 2. Inside.	No. 3. Inside.	No. 4. Inside.	No. 5. Outside.
Loss of weight.	G.	0·1694	0·1624	0·1535	0·1676	0·1608

Having thus found a satisfactory means of overcoming the difficulty under consideration, no further detailed study of the problem has been undertaken. The authors feel, however, that it

might prove to be an interesting subject for a separate investigation, and they hope to turn their attention to it again at some time in the future. They are certainly not at present in a position to offer a complete explanation of the changes that gave rise to the differences observed, but, they are inclined to think that the high percentage of phosphorus which is normally and intentionally present in tagger sheets is in some way responsible for it.

The Influence of Phosphorus upon the Rate of Attack by a 6% Solution of Sulphuric Acid in Water.

For the purpose of ascertaining the influence of varying percentages of phosphorus upon the rate of solubility in the two acid solutions already mentioned, a series of four steels was first made in which the carbon content was kept as low as possible, *viz.*, about 0·02%, while the phosphorus varied from 0·014 to 0·124%. These were made by melting Armco iron and adding the required amount of phosphorus in the form of phosphide of iron and commercially pure manganese; other elements were kept as low as possible. The chemical analyses of the samples were as follows:

Series 1.

Steel:	No. 1.	No. 2.	No. 3.	No. 4.
Carbon. %	0·017	0·017	0·019	0·023
Phosphorus. %	0·014	0·048	0·076	0·124
Sulphur. %	0·028	0·031	0·028	0·022
Manganese. %	0·27	0·26	0·27	0·26
Copper. %	0·071	0·071	0·071	0·071

As a matter of interest, it may be mentioned that no difficulty was experienced in getting the phosphorus content quite close to that which was aimed at. So far as could be gauged, there was no loss of this element during melting or after the phosphide additions were made. As will be noticed, the percentage of copper is, in all cases, approximately 0·075%. This represents the amount that was present in the Armco iron used. At a later stage in the investigations efforts were made to obtain a suitable raw material containing less copper, but, as indicated in due course, these were only partly successful. Tests were made at a number of temperatures, and losses of weight were observed after four different periods. The averages of three closely agreeing results are recorded in Table I. for the annealed samples and in Table II. for the corresponding samples examined in the cold-rolled condition. Since the character of the curves obtained by plotting the data for different temperatures on the one hand, and for varying periods of immersion on the other, are so similar, no useful purpose would be served by describing all the data; the main features are clearly revealed by plotting the results for a temperature of 25° C. after an immersion of 22 hr.

TABLE I.—0·02% *Carbon Steel, Annealed at* 950° *C.* 6% *Sulphuric Acid.*

Time. Hr.	Temp. ° C.	Loss of Weight. G. (Average of 3 Results.)			
		No. 1. 0·014% P.	No. 2. 0·048% P.	No. 3. 0·076% P.	No. 4. 0·124% P.
1	0	0·0008	0·0008	0·0009	0·0015
	25	0·0051	0·0125	0·0160	0·0148
	40	0·0170	0·0399	0·0602	0·0458
	60	0·1293	0·2722	0·4644	0·6252
	75	0·1902	0·6651	0·9293	1·1969
2	0	0·0013	0·0013	0·0011	0·0024
	25	0·0073	0·0201	0·0276	0·0278
	40	0·0391	0·0965	0·1684	0·1701
	60	0·2713	0·5918	0·9462	1·2601
	75	0·4884	1·4682	1·9312	2·5186
4	0	0·0022	0·0022	0·0033	0·0120
	25	0·0132	0·0458	0·0728	0·0934
	40	0·0813	0·2308	0·4027	0·4824
22	0	0·0078	0·0131	0·0323	0·1135
	25	0·1338	0·5083	0·9193	1·5409

TABLE II.—0·02% *Carbon Steel, Cold-Rolled.* 6% *Sulphuric Acid.*

Time. Hr.	Temp. ° C.	Loss of Weight. G. (Average of 3 Results.)			
		No. 1. 0·014% P.	No. 2. 0·048% P.	No. 3. 0·076% P.	No. 4. 0·124% P.
1	0	0·0004	0·0010	0·0013	0·0009
	25	0·0026	0·0029	0·0051	0·0119
	40	0·0083	0·0224	0·0332	0·0579
	60	0·0361	0·1444	0·2862	0·4108
	75	0·2287	0·7342	0·9820	1·2810
2	0	0·0011	0·0018	0·0020	0·0022
	25	0·0066	0·0079	0·0167	0·0415
	40	0·0242	0·0795	0·1264	0·1923
	60	0·1314	0·4664	0·7150	1·0280
	75	0·5433	1·5309	1·8953	2·3423
4	0	0·0024	0·0032	0·0031	0·0051
	25	0·0213	0·0300	0·0758	0·1451
	40	0·0792	0·2499	0·3673	0·5135
22	0	0·0253	0·0427	0·0626	0·1333
	25	0·2267	0·5982	0·9796	1·5685

The curves for both the cold-rolled and the annealed specimens are shown in Fig. 2, where the dotted line represents the former,

and the full line the latter. As will be seen, both sets of data can be represented by two perfectly straight lines. These are so close together as to make it quite evident that very heavy cold-rolling has little effect upon the rate at which these steels, containing very little carbon and up to 0·12% of phosphorus, are dissolved by a 6% solution of sulphuric acid in water. It is true, however, that

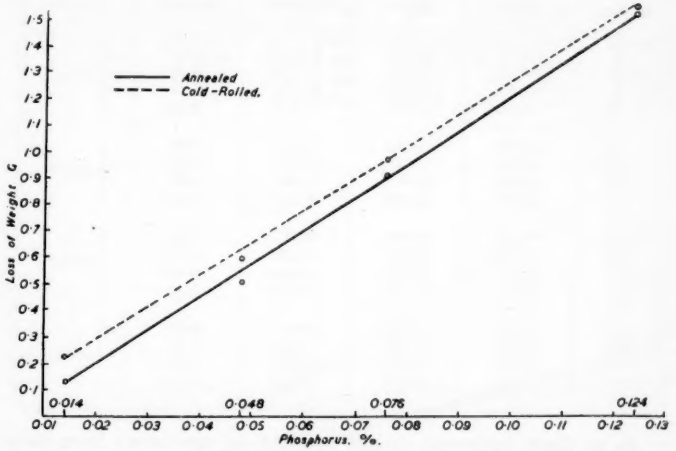

FIG. 2.—Phosphorus Series, 0·02% of carbon; 6% sulphuric acid, 22 hr. at 25° C.

there is a general indication that cold-rolling causes a slight acceleration in the rate, but, in the absence of any other evidence, the differences could be regarded as being within the range of experimental error. The really important point to observe, however, is that in the presence of only 0·02% of carbon, an increase of phosphorus from 0·014 to 0·124% causes a remarkable increase in the rate of acid attack; with the higher limit of phosphorus this is about ten times greater than that when only traces of phosphorus are present.

The Influence of Phosphorus in the Presence of Increasing Percentages of Carbon.

With the object of determining the influence of phosphorus in the presence of increasing percentages of carbon, three additional series of steel were made. In these, the carbon contents were respectively 0·08, 0·115 and 0·15%, while, as will be seen, the phosphorus contents were almost identical with the series already described.

As previously indicated, the control of the phosphorus contents was made easy by the fact that no loss of this element was experienced during melting. The chemical compositions of these three series of steels are given in Table III.

TABLE III.—*Analyses of Steels.*

Steel No.	Carbon. %	Sulphur. %	Phosphorus. %	Manganese. %	Copper. %
1	0·017	0·028	0·014	0·27	0·071
2	0·017	0·031	0·048	0·26	
3	0·019	0·028	0·076	0·27	
4	0·023	0·022	0·124	0·26	
5	0·082	0·015	0·015	0·31	0·075
6	0·080	0·017	0·047	0·33	
7	0·083	0·017	0·080	0·32	
8	0·078	0·020	0·118	0·34	
9	0·118	0·023	0·017	0·36	0·087
10	0·109	0·024	0·047	0·38	
11	0·119	0·024	0·084	0·38	
12	0·109	0·023	0·118	0·40	
13	0·152	0·024	0·017	0·36	0·080
14	0·147	0·023	0·050	0·36	
15	0·150	0·022	0·087	0·36	
16	0·152	0·021	0·122	0·39	

As in those instances already referred to, specimens from each of the above steels were examined in the fully annealed and the cold-rolled conditions. The data for each series are recorded in Tables IV. and V., and the results are plotted in Figs. 3, 4, 5, and 6. With regard to the results for the annealed samples, which are illustrated in Fig. 3, perhaps the most interesting feature revealed is that the presence of 0·08, 0·115 and 0·15% of carbon gives rise to a decided retardation in the rate of acid attack, as compared

TABLE IV.—*Steels, Annealed at* 950° *C.* 6% *Sulphuric Acid for* 22 *Hr. at* 25° *C.*

Loss of Weight. G. (Average of 3 Results.)								
Carbon 0·08%.			Carbon 0·115%.			Carbon 0·15%.		
No.	P. %	Loss.	No.	P. %	Loss.	No.	P. %	Loss.
5	0·015	0·0629	9	0·017	0·0782	13	0·017	0·0613
6	0·047	0·3752	10	0·047	0·4646	14	0·050	0·4197
7	0·080	0·5930	11	0·084	0·6153	15	0·087	0·6293
8	0·118	0·7914	12	0·118	0·7651	16	0·122	0·7138

TABLE V.—*Steels, Cold-Rolled.* 6% *Sulphuric Acid for* 22 *Hr. at* 25° *C.*

Loss of Weight. G. (Average of 3 Results.)								
Carbon 0·08%.			Carbon 0·115%.			Carbon 0·15%.		
No.	P. %.	Loss.	No.	P. %.	Loss.	No.	P. %.	Loss.
5	0·015	0·1849	9	0·017	0·2759	13	0·017	0·3001
6	0·047	0·4824	10	0·047	0·6486	14	0·050	0·6434
7	0·080	0·6842	11	0·084	0·7818	15	0·087	0·7716
8	0·118	0·7935	12	0·118	0·9768	16	0·122	0·8858

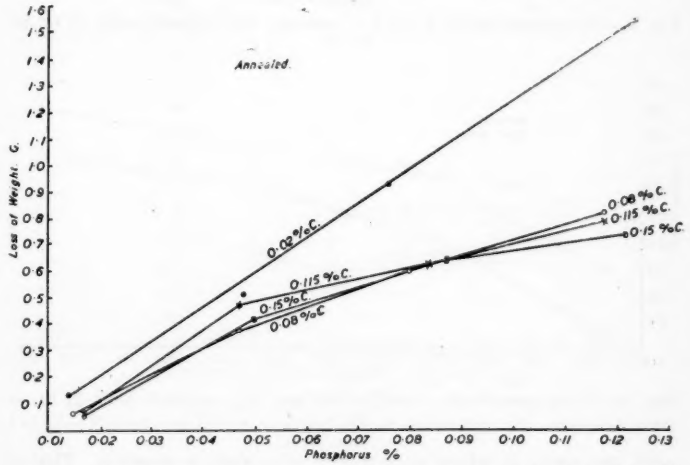

FIG. 3.—Phosphorus Series, varying carbon contents; 6% sulphuric acid, 22 hr. at 25° C.

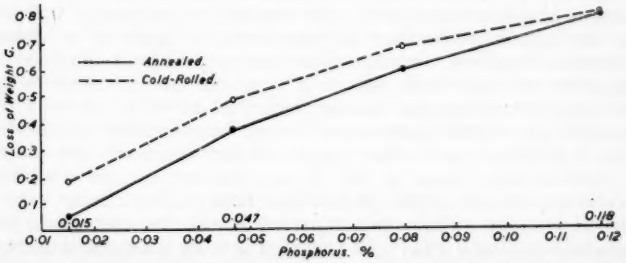

FIG. 4.—Phosphorus Series, 0·08% of carbon; 6% sulphuric acid, 22 hr. at 25° C.

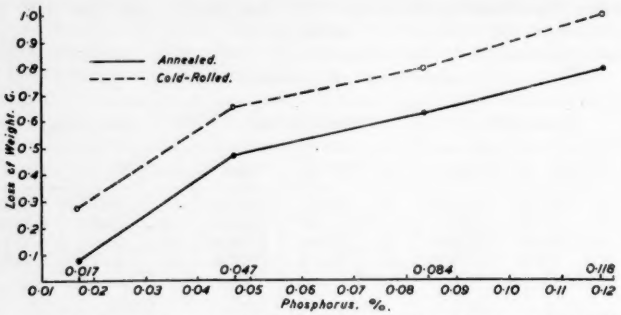

FIG. 5.—Phosphorus Series, 0·115% of carbon; 6% sulphuric acid, 22 hr. at 25° C.

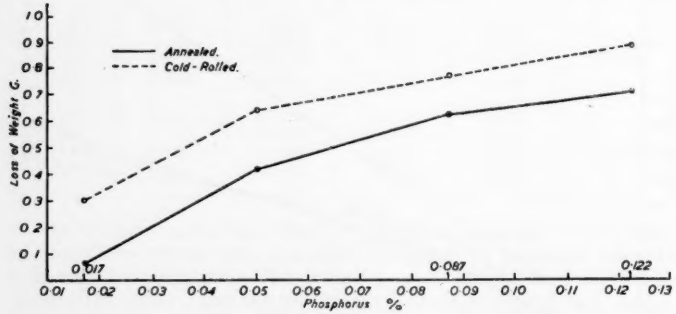

FIG. 6.—Phosphorus Series, 0·15% of carbon; 6% sulphuric acid, 22 hr. at 25° C.

with the series in which only 0·02% of carbon is present. This is more particularly marked when the phosphorus is above 0·048%. It will also be observed that in all three series in which the carbon content is greater than 0·08% the results are practically the same for any given percentage of phosphorus. There is a distinct difference, however, between these curves and that obtained for the series of steels with only 0·02% of carbon. In other words, the effect of raising the carbon from 0·02 to 0·08% is very pronounced, but further increases of carbon have little or no influence. This is rendered much more obvious when the results are plotted in another way; thus, in Fig. 7 the data for samples containing similar percentages of phosphorus have been plotted against varying carbon content. From this diagram it will be seen that, with samples containing 0·124% of phosphorus there is a marked decrease in the rate of solution on raising the carbon from 0·02 to 0·08%;

similar indications are to be seen in the other curves, but in those for the series containing 0·014 and 0·048% of phosphorus it is only just perceptible.

From a study of these curves (Fig. 7) it seems quite evident that great caution must be exercised in drawing conclusions concerning the influence of some elements in steel upon the rate of acid attack if the carbon present in different samples happens to vary much between the limits of 0·02 and 0·08%. This is a matter of some importance, especially when it is remembered how easily variations in the carbon content of even greater magnitude can be brought

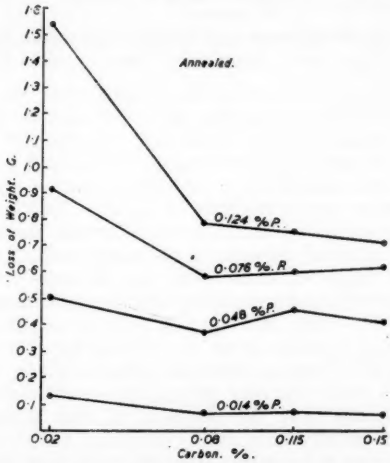

FIG. 7.—Phosphorus Series, varying carbon contents; 6% sulphuric acid, 22 hr. at 25° C.

about in the surface during annealing operations. At this stage it should, perhaps, be mentioned that the effects of carbon noted above are not as surprising as might first appear. There is every reason for believing that the retardation of solution brought about by 0·08% of carbon and upwards is largely due to the formation of a protective coating, or crust, upon the surface of the specimen which consists of a decomposition product of carbide of iron. This coating prevents the solution from getting into such intimate contact with the surface of the metal itself.

Influence of Cold-Rolling.

The influence of cold-rolling upon the rate of attack in a 6% solution of sulphuric acid in water at 25° C. will now be considered. As previously mentioned, the results for these tests are given in

Tables II. and V., and they are shown diagrammatically in Figs. 2, 4, 5, and 6. With the series containing only 0·02% of carbon and up to 0·124% of phosphorus, heavy cold-rolling causes a small increase in the rate of solution (Fig. 2). Generally speaking, however, the difference in this direction is somewhat greater in the series containing 0·08% of carbon (Fig. 4), and again still more marked when the carbon is 0·115 and 0·15%, as will be seen in Figs. 5 and 6. Apart from these general statements of facts, it is unnecessary, at this stage, to discuss the effects of cold-rolling upon those steels containing varying quantities of phosphorus and carbon.

The Influence of Phosphorus and Carbon upon the Rate of Attack on Steel by a 2·0% Solution of Citric Acid in Water.

With the object of throwing some light upon the relationship between the chemical composition of a steel and its suitability for tinplate which is to be used in certain branches of the canning industry, previous investigators (notably Morris and Bryan (*loc. cit.*) and Hoar and Havenhand (*loc. cit.*)) have used a 2% solution of citric acid in water as the medium of attack. In view of this, the authors considered it very desirable to determine the rate of action of such a citric acid solution on all the steels made for the present work. In this range of their work, the authors were, perhaps, rather too anxious to get something like the same degree of attack when using the 2% citric acid solution as they had observed with a 6% sulphuric acid solution at 25° C. It was for this reason that a temperature of 75° C. and an ultimate period of 22 hr. were adopted for those steels with varying phosphorus and carbon contents. Later it was found that the selection of this temperature was unfortunate for strictly comparative purposes, but it can be stated that the conclusions to be drawn from the results are much the same as those for a temperature of 25° C. and a period of attack of 96 hr.

Annealed Specimens.—The data obtained for the annealed specimens are given in Table VI., and they have been plotted on separate curves for each series in Figs. 8, 9, 10 and 11. Here it will

TABLE VI.—*Steels, Annealed at 950° C. 2% Citric Acid for 22 Hr. at 75° C.*

Loss of Weight. G. (Average of 3 Results.)												
Carbon 0·02%.			Carbon 0·08%.			Carbon 0·115%.			Carbon 0·15%.			
No.	P. %.	Loss.	No.	P. %.	Loss.	No.	P. %.	Loss.	No.	P. %.	Loss.
1	0·014	0·6882	5	0·015	0·7598	9	0·017	0·7696	13	0·017	0·6890
2	0·048	1·0277	6	0·047	1·0507	10	0·047	1·1325	14	0·050	0·9952
3	0·076	1·1447	7	0·080	1·1039	11	0·084	1·1105	15	0·087	0·9963
4	0·124	1·2475	8	0·118	1·1378	12	0·118	1·1271	16	0·122	1·0045

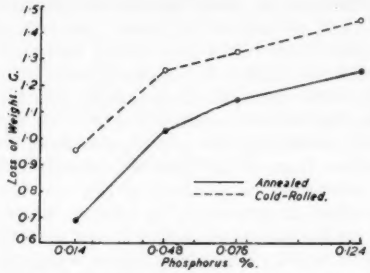

FIG. 8.—Phosphorus Series, 0·02% of carbon; 2% citric acid, 22 hr. at 75° C.

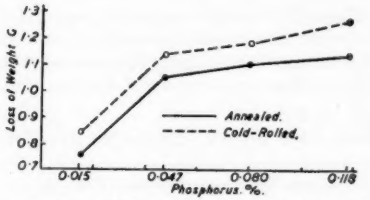

FIG. 9.—Phosphorus Series, 0·08% of carbon; 2% citric acid, 22 hr. at 75° C.

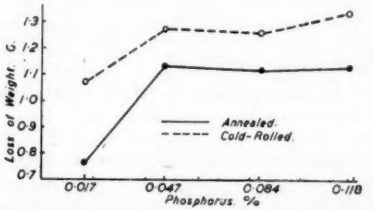

FIG. 10.—Phosphorus Series, 0·115% of carbon; 2% citric acid, 22 hr. at 75° C.

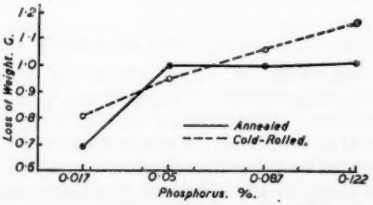

FIG. 11.—Phosphorus Series, 0·15% of carbon; 2% citric acid, 22 hr. at 75° C.

be seen that, in the case of those specimens containing only 0·02% of carbon, the rate of attack increases quite rapidly when the phosphorus is raised from 0·014 to 0·048%, and this tendency continues, but a little less quickly, as the phosphorus is further increased to 0·124%. The same general observations can be said to apply to the curve for the series containing 0·08% of carbon, with the qualification that increasing the phosphorus from 0·048 to 0·124% has much less effect than in the presence of only 0·02% of carbon. In both series containing respectively 0·115 and 0·15% of carbon, much the same effect is produced by raising the phosphorus from 0·014 to 0·048% as for those containing lower percentages of carbon already referred to, but by increasing the phosphorus above 0·048% in these instances no greater acid attack is brought about.

Cold-Rolled Specimens.—The results are recorded in Table VII., and the curves are plotted in Figs. 8, 9, 10 and 11 for each individual series alongside those for the corresponding annealed samples.

For the series with the lowest percentage of carbon (0·02%), it will be seen (Fig. 8) that cold-rolling has caused the rate of attack to be slightly higher than was observed for the annealed samples.

TABLE VII.—*Steels, Cold-Rolled. 2% Citric Acid for 22 Hr. at 75° C.*

Loss of Weight. G. (Average of 3 Results.)												
Carbon 0·02%.			Carbon 0·08%.			Carbon 0·115%.			Carbon 0·15%.		
No.	P. %.	Loss.	No.	P. %.	Loss.	No.	P. %.	Loss.	No.	P. %.	Loss.
1	0·014	0·9591	5	0·015	0·8442	9	0·017	1·0758	13	0·017	0·8068
2	0·048	1·2589	6	0·047	1·1385	10	0·047	1·2735	14	0·050	0·9491
3	0·076	1·3247	7	0·080	1·1810	11	0·084	1·2599	15	0·087	1·0562
4	0·124	1·4435	8	0·118	1·2640	12	0·188	1·3312	16	0·122	1·1538

With those steels containing respectively 0·08 and 0·115% of carbon, the effects of cold-rolling are much the same as for the series just referred to, as will be seen from Figs. 9 and 10. In the case of steels containing 0·15% of carbon it will be noticed that the results for the cold-rolled specimens do not appear to reveal so close a relationship to those for the annealed samples.

Rate of Attack by Citric Acid at 25° C.

A series of tests with 2% citric acid at 25° C. was made with those steels containing 0·02% of carbon and phosphorus varying from 0·014 to 0·124%. The primary object in this instance was to obtain evidence that would reveal the influence of the temperature which had been used by other investigators, as well as by the present workers in their study of the influence of sulphur and copper. The results for both the annealed and the cold-rolled states are recorded

in Table VIII., whilst the corresponding curves are shown in Fig. 12. Here it will be seen that an increase in the phosphorus causes a marked increase in the rate of acid attack—in both the annealed and the cold-rolled conditions. On comparing the curve for the annealed samples (Fig. 12) with those for a temperature of 75° C. (Fig. 8), it will be noticed that the characters of the two curves are different, that for the lower temperature being concave and that for the higher temperature convex.

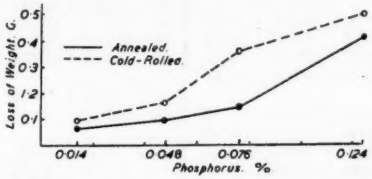

FIG. 12.—Phosphorus Series, 0·02% of carbon; 2% citric acid, 96 hr. at 25° C.

TABLE VIII.—0·02% *Carbon Steel.* 2% *Citric Acid for* 96 *Hr. at* 25° *C.*

No.	P. %.	Loss of Weight. G. (Average of 3 Results.)	
		Annealed at 950° C.	Cold-Rolled.
1	0·014	0·0636	0·0985
2	0·048	0·0987	0·1625
3	0·076	0·1407	0·3506
4	0·124	0·4062	0·4918

The Influence of Varying Sulphur and Copper upon the Rate of Attack by Solutions of Sulphuric and Citric Acids.

In planning the work for the study of the influence of sulphur and copper, it was decided to make steels in which the carbon and phosphorus contents were kept as low as possible, while efforts were made to keep the manganese at approximately 0·40%. By using Armco iron as the raw material no difficulty was experienced with regard to carbon and phosphorus, but, owing to oxidation losses, it was not possible to obtain perfectly regular contents of manganese. Nevertheless, as will be seen from the analyses given in Table IX., the differences in the percentages of this element are reasonably small. With regard to sulphur and copper, the aim was to make a number of series of steels in which the copper for each particular series was constant while the sulphur varied. In doing this, efforts were made to have the sulphur contents so arranged that, in the majority of instances, each particular sample

TABLE IX.—*Analyses of the Steels in the Copper-Sulphur Series.*

No.	Copper. %	Sulphur. %	Phosphorus. %	Manganese. %	No.	Copper. %	Sulphur. %	Phosphorus. %	Manganese. %
17	0·005	0·012	0·025	0·46	29	0·145	0·028	0·020	0·34
18	0·005	0·087	0·028	0·39	30	0·139	0·068	0·023	0·38
					31	0·156	0·107	0·013	0·39
19	0·049	0·018	0·025	0·49	32	0·140	0·127	0·017	0·40
20	0·050	0·099	0·025	0·45					
					33	0·236	0·024	0·018	0·38
21	0·072	0·019	0·017	0·46	34	0·236	0·063	0·016	0·40
22	0·075	0·057	0·015	0·44	35	0·240	0·107	0·014	0·31
23	0·082	0·100	0·012	0·42	36	0·248	0·150	0·013	0·36
24	0·088	0·143	0·012	0·41					
					37	0·005	0·099	0·025	0·49
25	0·110	0·019	0·014	0·49	38	0·005	0·149	0·023	0·49
26	0·117	0·065	0·014	0·46					
27	0·119	0·090	0·016	0·43	39	0·050	0·101	0·020	0·49
28	0·112	0·135	0·022	0·40	40	0·053	0·140	0·019	0·49

containing a given percentage of sulphur in one series (of constant copper content) had its counterpart in each of the other copper series. In this way, it was expected that it would be possible to examine the results from the point of view of the influence of varying sulphur in the different series containing constant percentages of copper, and similarly the influence of varying copper in the presence of constant percentages of sulphur. Needless to say, this object was not achieved with perfect satisfaction, but, as will be seen from a glance at the analyses (Table IX.) the deviations are within reasonable limits and indicate that the attempt was justified.

The details concerning the preparation of the samples for acid attack were, with one exception, similar to those already described in connection with the phosphorus specimens. There was, however, one intentional difference, namely, with these samples the material in the hot-rolled condition was pickled and then annealed before cold-rolling, whereas the previous series had been annealed, then pickled and dried, prior to cold-rolling. This change of procedure was adopted because in steels containing much copper there is a tendency for copper to be deposited on the surface of the specimens during pickling in sulphuric acid, but by subsequent annealing, this film of copper quickly diffuses into the sample.

The Influence of Sulphur in Series containing approximately Constant Percentages of Copper upon the Rate of Attack by a 6% Solution of Sulphuric Acid in Water at 25° C. Annealed Samples.

The test results are recorded in Table X. and depicted in the two sets of curves in Fig. 13, one of which relates to a period of attack of 24 hr. and the other to 96 hr. From the short-period

curves it will be observed that steels in the series containing the lowest percentage of copper (0·07%) show a consistently greater rate of attack than those in any of the other three series. There is an indication of a slight increase in the rate of attack when the sulphur is raised from 0·024 to 0·063%, but this can be regarded

TABLE X.—*Copper-Sulphur Series, Annealed at 950° C. 6% Sulphuric Acid for 24 and 96 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)							
Copper 0·075%.				Copper 0·115%.			
No.	S. %.	Loss.		No.	S. %.	Loss.	
		24 Hr.	96 Hr.			24 Hr.	96 Hr.
21	0·019	0·1336	0·6686	25	0·019	0·0866	0·4674
22	0·057	0·1498	0·7172	26	0·065	0·0873	0·4972
23	0·100	0·1422	0·6665	27	0·090	0·0963	0·5060
24	0·143	0·1491	0·6792	28	0·135	0·1062	0·5343
Copper 0·140%.				Copper 0·24%.			
No.	S. %.	Loss.		No.	S. %.	Loss.	
		24 Hr.	96 Hr.			24 Hr.	96 Hr.
29	0·028	0·0813	0·4684	33	0·024	0·0478	0·3025
30	0·068	0·0867	0·4623	34	0·063	0·0744	0·3918
31	0·107	0·0777	0·4414	35	0·107	0·0815	0·3963
32	0·127	0·0927	0·4728	36	0·150	0·0854	0·4114

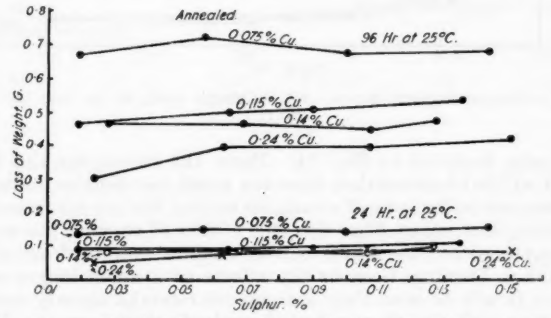

FIG. 13.—Copper-Sulphur Series; 6% sulphuric acid, 24 hr. and 96 hr. at 25° C.

as almost within the range of experimental error; further increases in the sulphur do not appear to have any effect.

With the series of samples containing respectively 0·11 and 0·14% of copper the rate of attack is less than that for those just referred to; when considered amongst themselves, there is practically no difference due to a variation of sulphur between the limits of 0·02 and 0·15%. With specimens containing 0·25% of copper, it will be seen from the curves that this extra copper coincides with a reduction in the rate of attack in the lower ranges of sulphur but not in the higher sulphur range. The results obtained with a period of immersion of 96 hr. have also been incorporated in Fig. 13 for comparison with those just discussed. From these it will be noticed that this increase in the time has not altered the general character of the curves.

The Influence of Increases in the Copper with Approximately Constant Sulphur Contents.

The data already dealt with have been plotted again in another way; the curves obtained illustrate the influence of increasing percentages of copper in the presence of constant percentages of sulphur. Both periods of immersion, namely, 24 and 96 hr., are

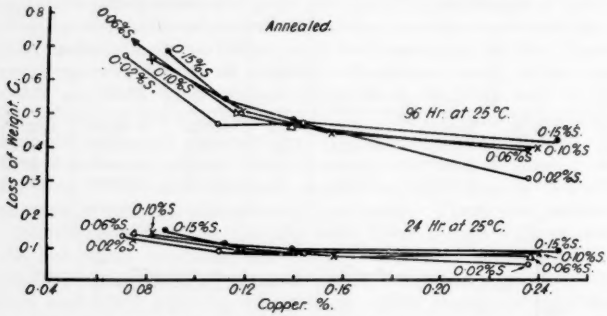

FIG. 14.—Copper-Sulphur Series; 6% sulphuric acid, 24 hr. and 96 hr. at 25° C.

graphically depicted in Fig. 14. From the curves for the 24-hr. tests, it will be observed that there is a small, but definite, indication of a decrease in the rate of attack on raising the copper from 0·075 to 0·115%, but, apart from this, the effects of varying the sulphur and copper within the limits of the samples examined are almost negligible. Turning, now, to the effects of a much longer period (96 hr.), it will be seen that the general remarks already made in connection with the shorter period apply to these curves. It can, however, be stated that the general indications or tendencies are

brought out in a much more accentuated form in these latter curves. Perhaps the most important point to note is that there appears to be a very clearly defined break at about 0·11–0·14% of copper.

Annealed Samples. The Influence of Copper in the Presence of Low Percentages of Impurities.

At this stage, it may be useful to emphasise clearly the influence of varying percentages of copper itself upon the rate at which low-carbon iron-copper alloys are dissolved in a 6% solution of sulphuric acid in water. With this end in view, two additional samples were made, containing lower percentages of copper than any of those previously referred to. For this purpose, Swedish bar iron, which was kindly provided by Dr. W. H. Hatfield, F.R.S., was used as the raw material. In making these casts slight modifications of procedure during melting were adopted, but the authors feel satisfied that these changes have not affected the value of the results obtained from those samples which were tested in the annealed condition. This does not appear to be the case for those samples which were tested in the cold-rolled state. At this stage, however, no useful purpose would be served by describing the details of melting procedure, &c., mentioned above; this will be done later, when the questions that emerge become of more immediate interest.

The two additional samples that were made for the purpose under consideration contained, respectively, 0·005 and 0·05% of copper; they were rolled and prepared for examination in acid solutions in the customary manner. The results are shown in Table XI.

TABLE XI.—*Copper-Sulphur Series, Annealed at 950° C. 6% Sulphuric Acid.*

Copper. %.	No.	S. %.	Loss of Weight. G. (Average of 3 Results.)	
			96 Hr. at 25° C.	48 Hr. at 25° C.
0·005	17	0·012	Dissolved in 72 hr.	1·7541
0·05	19	0·018	1·3651	0·5712

It was found that the sample with only 0·005% of copper was almost completely dissolved after an immersion of 72 hr. in 6% sulphuric acid at 25° C. The diagram obtained with this additional evidence is given in Fig. 15. This curve gives clear confirmation of the indications previously obtained, that the introduction and increase of copper up to something between, say, 0·075 and 0·115% produces a very rapid decrease in the rate at which otherwise almost pure iron (apart from the presence of, say, 0·4% of manganese) is dissolved in a 6% solution of sulphuric acid. It will be seen later

that the exact percentage of copper which corresponds with the break in the rate-of-solution curve apparently depends to some extent upon the length of time that the attack is allowed to proceed.

A similar set of curves for samples containing respectively 0·02, 0·10 and 0·15% of sulphur and copper from 0·005 to 0·25% for a period of attack of 24 hr. at 25° C. is shown in Fig. 16; the data are contained in Tables X. and XII. The characters of the

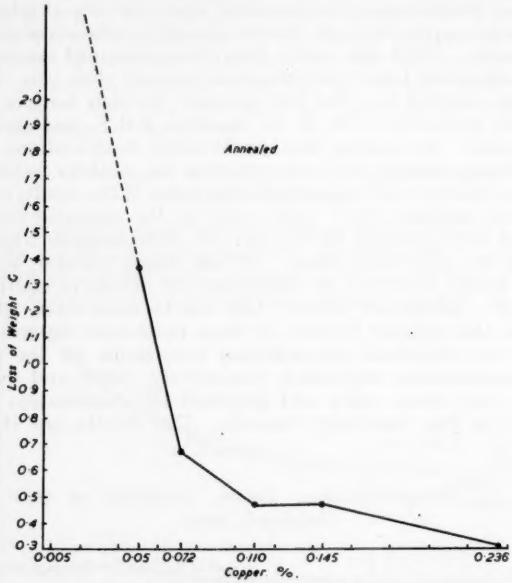

FIG. 15.—Copper-Sulphur Series, 0·02% of sulphur; 6% sulphuric acid, 96 hr. at 25° C.

TABLE XII.—*Copper-Sulphur Series, Annealed at 950° C. 6% Sulphuric Acid for 24 Hr. at 25° C.*

Loss of Weight. G. Average of 3 Results.)					
Copper 0·005%.			Copper 0·05%.		
No.	S. %.	Loss.	No.	S. %.	Loss.
17	0·012	0·6406	19	0·018	0·1092
18	0·087	1·1304	20	0·099	0·1760
38	0·149	1·7306	40	0·140	0·1750

curves are very similar, but it is clear that in the presence of only 0·005% of copper the rate of solution becomes much greater as the percentage of sulphur increases. These differences are very materially reduced when the copper is raised to about 0·05%. Raising the copper from 0·05 to 0·12% causes a further relatively small decrease in the rate of attack, after which there is practically no difference in the behaviour of any of the samples.

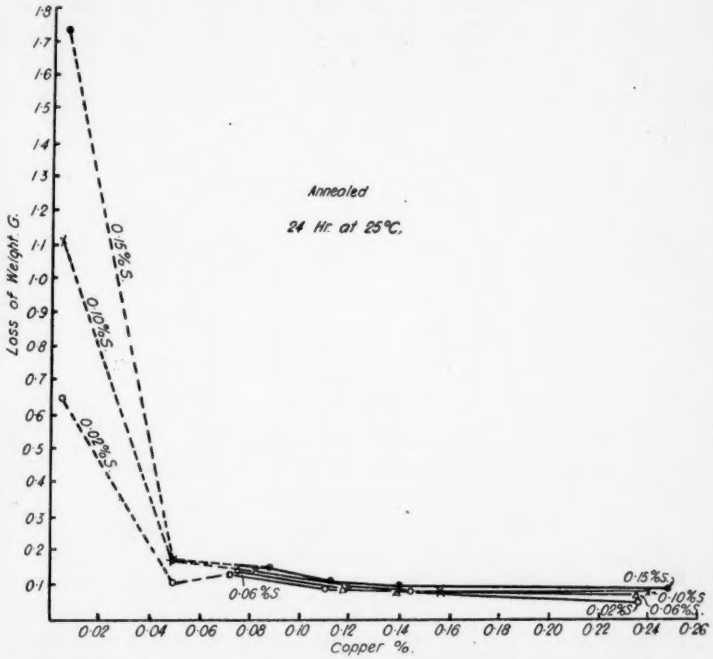

FIG. 16.—Copper-Sulphur Series; 6% sulphuric acid, 24 hr. at 25° C.

Another set of data for a series of samples with low sulphur contents and, say, 0·02% and 0·08% of carbon and copper varying from 0·05 to 0·57% are shown in Table XIII. and Fig. 17. These curves represent the influence of attack for 22, 72, 96, and 120 hr. at 25° C., another for 4 hr. at 75° C., another for 4 hr. at 60° C. and the last for 22 hr. at 40° C. Apart from the fact that a period of 22 hr. at 25° C. does not appear to be long enough to reveal the influence of copper, it may be concluded that quite wide variations of time and temperature have very little effect upon the character

TABLE XIII.—*Copper Series, containing* 0·08% *of Carbon and* 0·02% *of Sulphur, Annealed at* 950° *C. Sulphuric Acid.*

Time. Hr.	Temperature. ° C.	Loss of Weight. G. (Average of 3 Results.)					
		0·05% Cu.	0·12% Cu.	0·19% Cu.	0·33% Cu.	0·46% Cu.	0·57% Cu.
22	25	0·0726	0·0843	0·0774	0·0829	0·0873	0·0784
72	25	0·5392	0·3026	0·3123	0·2860	0·3706	0·3626
96	25	0·9987	0·4758	0·4597	0·4230	0·4885	0·4829
120	25	1·3760	0·6638	0·5984	0·5509	0·6288	0·6245
22	40	0·4628	0·3162	0·3023	0·3033	0·2975	0·2896
4	60	0·2739	0·2163	0·2115	0·2141	0·2469	0·2397
4	75	1·2136	0·6325	0·6004	0·5466	0·5475	0·5279

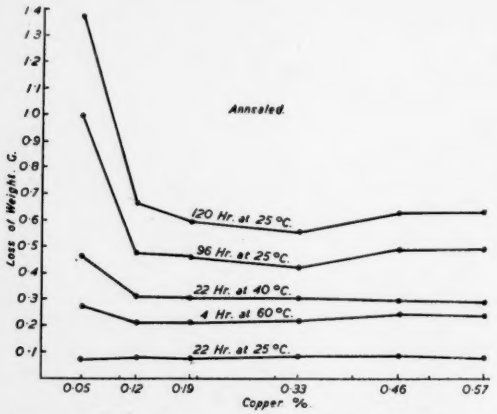

FIG. 17.—Copper-Sulphur Series; 6% sulphuric acid, various periods and temperatures.

of the curves; but after prolonged attack the effect of copper becomes strikingly evident.

The Influence of Varying Sulphur and Copper. Consideration of the Results for Annealed Samples in a 2% *Solution of Citric Acid for* 96 *Hr.*

In the first instance, the results recorded in Table XIV. have been plotted for those specimens containing similar quantities of copper against varying percentages of sulphur. These will be seen in Fig. 18, from which it will be noticed that there is a general tendency for the rate of attack to decrease slightly with an increase in the sulphur from 0·024 to 0·063%, after which all the other

differences that are evident can be regarded as being well within the limits of experimental error. For the purpose of depicting the influence of copper, the same data have been used along with those obtained from additional samples containing still lower percentages of copper. The curves are shown in Fig. 19, and the results are recorded in Tables XIV. and XV., from which it will be

TABLE XIV.—*Copper-Sulphur Series. Annealed at 950° C. 2% Citric Acid for 96 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)											
Copper 0·075%.			Copper 0·115%.			Copper 0·140%.			Copper 0·240%.		
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.
21	0·019	0·0838	25	0·019	0·0874	29	0·028	0·0998	33	0·024	0·1110
22	0·057	0·0769	26	0·065	0·0642	30	0·068	0·0742	34	0·063	0·0830
23	0·100	0·0733	27	0·090	0·0701	31	0·107	0·0782	35	0·107	0·0708
24	0·143	0·0785	28	0·135	0·0679	32	0·127	0·0741	36	0·150	0·0737

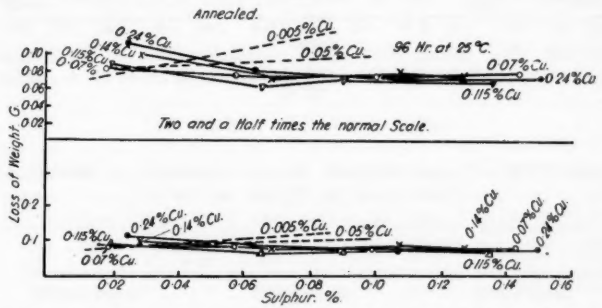

FIG. 18.—Copper-Sulphur Series; 2% citric acid, 96 hr. at 25° C.

TABLE XV.—*Copper-Sulphur Series, Annealed at 950° C. 2% Citric Acid for 96 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)					
Copper 0·005%.			Copper 0·05%.		
No.	S. %.	Loss.	No.	S. %.	Loss.
17	0·012	0·0700	19	0·018	0·0822
18	0·087	0·1286	20	0·099	0·1012
37 *	0·099	0·0971	39 *	0·101	0·0871
38 *	0·149	0·1532	40 *	0·140	0·0955

* With added alumina.

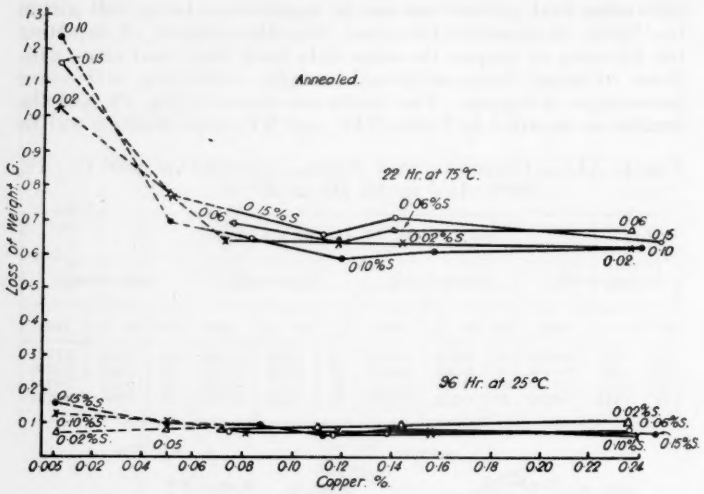

FIG. 19.—Copper-Sulphur Series; 2% citric acid, 96 hr. at 25° C., 22 hr. at 75° C.

TABLE XVI.—*Copper-Sulphur Series, Annealed at 950° C. 2% Citric Acid for 22 Hr. at 75° C.*

Loss of Weight. G. (Average of 3 Results.)

Copper 0·005%.			Copper 0·05%.			Copper 0·075%.		
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.
17	0·012	1·0270	19	0·019	0·7795	21	0·019	0·6425
...	...	...	...	...	...	22	0·057	0·6942
18	0·087	1·2359	20	0·099	0·6960	23	0·100	0·6435
38	0·149	1·1529	40	0·140	0·7749	24	0·143	0·6996

Copper 0·115%.			Copper 0·140%.			Copper 0·240%.		
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.
25	0·019	0·6389	29	0·028	0·6400	33	0·024	0·6221
26	0·065	0·6325	30	0·068	0·6726	34	0·063	0·6720
27	0·090	0·5813	31	0·107	0·6073	35	0·107	0·6257
28	0·135	0·6581	32	0·127	0·7082	36	0·150	0·6458

seen that, apart from those samples containing only 0·005% of copper, quite wide variations in the percentage of that element are almost without any influence when the specimens are treated in a 2% citric acid solution at 25° C. for 96 hr.

In order to bring out more clearly the influence of copper upon the rate of attack in a 2% solution of citric acid, it was decided to carry out a series of experiments at 75° C. for 22 hr. The results are given in Table XVI. and are plotted in the upper part of Fig. 19. Under these conditions, it is very clearly shown that there is a marked drop in the rate of attack when the copper is increased from 0·005 to 0·05%. Apart from this, however, the influence of copper in any given sulphur series is very small.

Copper-Sulphur Series.

Cold-Rolled Samples Treated in a 6% Sulphuric Acid Solution.—For this purpose, the specimens were given an elongation of 100% by cold-rolling, and after cleaning in the usual manner they were tested in the sulphuric acid solution at 25° C. The results are given in Table XVII. and illustrated in four different curves in

TABLE XVII.—*Copper-Sulphur Series, Cold-Rolled. 6% Sulphuric Acid for 24 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)												
Copper 0·075%.			Copper 0·115%.			Copper 0·140%.			Copper 0·240%.		
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.
21	0·019	0·2345	25	0·019	0·1134	29	0·028	0·1222	33	0·024	0·0905
22	0·057	0·3389	26	0·065	0·2038	30	0·068	0·1284	34	0·063	0·1116
23	0·100	0·3576	27	0·090	0·2555	31	0·107	0·1648	35	0·107	0·1138
24	0·143	0·3467	28	0·135	0·3205	32	0·127	0·1691	36	0·150	0·1216

Copper 0·005%.						Copper 0·05%.					
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.
17	0·012	1·0642	...	...	...	19	0·018	0·3785	...	...	...
...	...	...	...	...	...	...	...	...	...	...	...
18	0·087	2·2904	37*	0·099	1·9621	20	0·099	1·1472	39*	0·101	1·8156
...	...	...	38*	0·149	2·5332	...	...	...	40*	0·140	2·1384

* With added alumina.

Fig. 20. Concerning the series containing 0·075% of copper, it may be stated that where only 0·024% of sulphur is present, the cold-rolling has caused the rate of attack to be almost doubled, as compared with the corresponding result obtained from the sample in the annealed state (*see* Fig. 13); further, the effects of this kind of

rolling are even more marked when the sulphur is raised to 0·063% and over. There is, however, little or no difference in the results obtained from cold-rolled samples containing from 0·063 to 0·15% of sulphur.

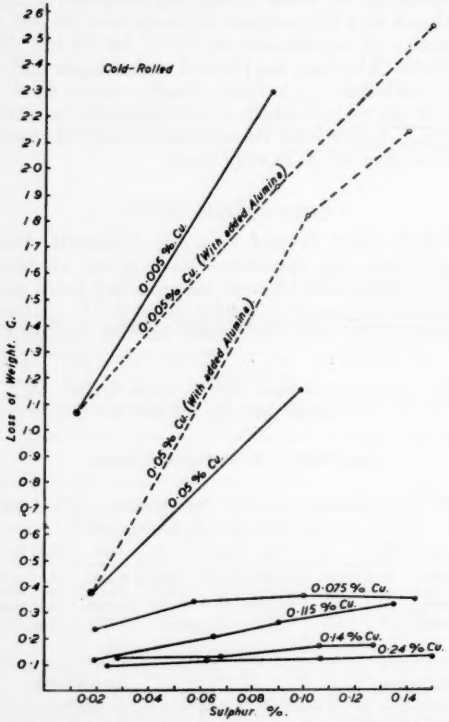

FIG. 20.—Copper-Sulphur Series; 6% sulphuric acid, 24 hr. at 25° C.

With regard to the series containing 0·11% of copper, it may be noted that with 0·024% of sulphur the effects of cold-rolling are much less pronounced than for the corresponding sample containing less copper (*i.e.*, 0·07%). Even in this series, however, when the sulphur is increased to 0·06% and over, cold-rolling does cause an increase in the rate of attack (as compared with that observed for annealed specimens), much the same as was noticed for the series just mentioned.

In the remaining two series, containing respectively 0·14 and 0·24% of copper, the influence of cold-rolling is much less evident

than in those containing lower copper. Indeed, when the results for these samples are compared with those of the corresponding annealed specimens, it will be noticed that there is not only little difference, but variations of sulphur between the limits of 0·024 and 0·15% have only a very small influence.

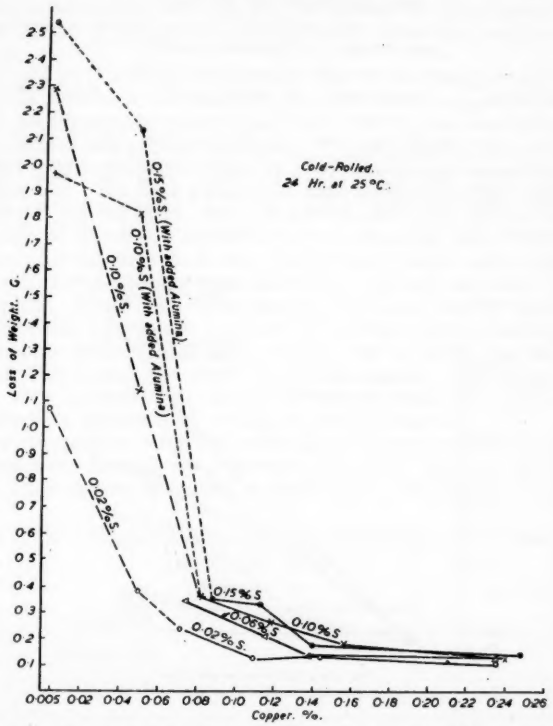

FIG. 21.—Copper-Sulphur Series; 6% sulphuric acid, 24 hr. at 25° C.

When the results just discussed are plotted in another way (*i.e.*, in series containing constant sulphur with varying copper), the influence of copper (and cold-rolling) can be more easily visualised. This has been done in Fig. 21, from which it will be seen that the effect of cold-rolling in increasing the rate of attack by sulphuric acid becomes greater as the percentage of sulphur increases, but that this tendency is diminished in all cases as the amount of copper present is raised. The influence of copper, in

this connection, appears to reach a maximum at about 0·115% when only 0·02% of sulphur is present, and at about 0·14% with from, say, 0·06 to 0·15% of sulphur.

TABLE XVIII.—*Copper-Sulphur Series, Cold-Rolled. 2% Citric Acid for 96 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)												
Copper 0·075%.			Copper 0·115%.			Copper 0·140%.			Copper 0·240%.			
No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.	No.	S. %.	Loss.	
21	0·019	0·0881	25	0·019	0·0804	29	0·028	0·0957	33	0·024	0·1019	
22	0·057	0·2014	26	0·065	0·1265	30	0·068	0·1138	34	0·063	0·0905	
23	0·100	0·2831	27	0·090	0·2082	31	0·107	0·1357	35	0·107	0·0955	
24	0·143	0·3557	28	0·135	0·2725	32	0·127	0·1331	36	0·150	0·1049	

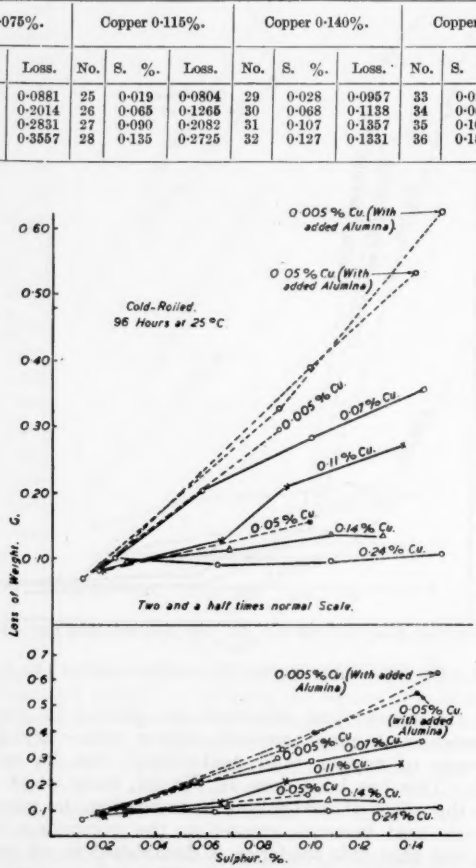

FIG. 22.—Copper-Sulphur Series; 2% citric acid, 96 hr. at 25° C.

Cold-Rolled Specimens Treated with Citric Acid Solution.—For samples containing 0·02–0·15% of sulphur and 0·07–0·24% of copper, much the same general conclusions concerning the rates of attack of cold-rolled specimens in citric acid solutions can be drawn as for similar samples tested in sulphuric acid.

The results are given in Table XVIII., and plotted in Fig. 22. A comparison of Fig. 22 with Fig. 20 reveals the close resemblances in the forms of the curves obtained with citric and sulphuric acid attack.

It was at this stage of the work that it was thought to be very desirable to extend the range of observations to samples containing lower percentages of copper than, say, 0·07%, the object being to find whether the general tendency of a diminution in the copper content to give rise to increased rates of attack would be still further accentuated. For this purpose, a new kind of raw material was required. Dr. Hatfield very kindly supplied the authors with a quantity of Swedish Lancashire iron containing only 0·005% of copper. In the first place two special casts were made from this material, one containing approximately 0·02 and the other 0·10% of sulphur. Later, two other charges were cast from a mixture of 50% Swedish Lancashire iron and 50% Armco iron, which gave a final copper content of 0·05%. Again, one of these was made to contain 0·02% and the other 0·10% of sulphur. All these specimens were hot-rolled in the usual manner, and then cold-rolled samples were prepared by rolling to 100% extension.

For comparison with the material previously referred to, these samples were treated by immersion in citric acid for 96 hr. at 25° C. The results are given in Table XIX. and plotted in dotted

TABLE XIX.—*Copper-Sulphur Series, Cold-Rolled. 2% Citric Acid for 96 Hr. at 25° C.*

Loss of Weight. G. (Average of 3 Results.)					
Copper 0·005%.			Copper 0·05%.		
No.	S. %.	Loss.	No.	S. %.	Loss.
17	0·012	0·0683	19	0·018	0·0825
18	0·087	0·2907	20	0·099	0·1544
37 *	0·099	0·3261	39 *	0·101	0·3889
38 *	0·149	0·6136	40 *	0·140	0·5315

* With added alumina.

lines in Fig. 23. It will be seen that for cold-rolled samples containing 0·02% of sulphur the rates of attack on the low-copper specimens are about the same as for those with higher percentages of copper. With the samples containing 0·10% of sulphur, however,

a rather remarkable break in what might be regarded as the normal trend of the curve was obtained. In other words, instead of a decrease in the copper content from 0·075 to 0·05% causing an increase in the rate of attack, a decrease was observed, thus:

Sample No.	Sulphur. %.	Copper. %.	Loss of Weight. G.
23	0·10	0·075	0·2831
20	0·099	0·05	0·1544

It is true that a further reduction in the copper to 0·005% in the presence of 0·10% of sulphur gave an increase in the rate of attack, thus:

Sample No.	Sulphur. %	Copper. %	Loss of Weight. G.
18	0·087	0·005	0·2907

These rather unexpected results from the use of Swedish Lancashire iron were disconcerting, and appeared to call for some further consideration.

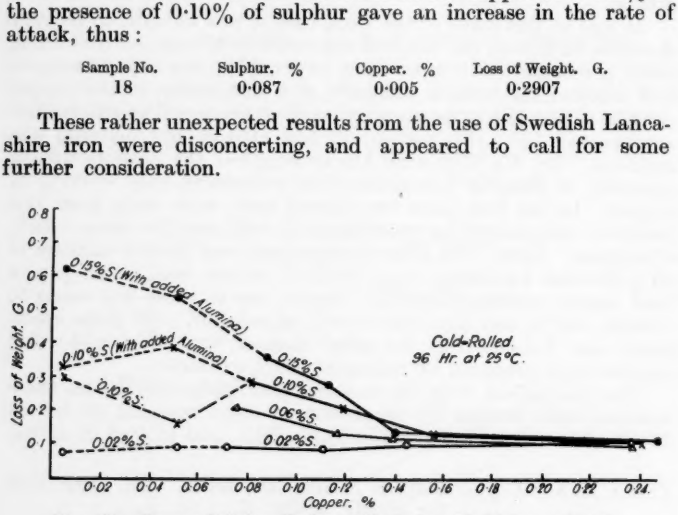

FIG. 23.—Copper-Sulphur Series; 2% citric acid, 96 hr. at 25° C.

In their extended examination of this particular aspect of the problem, the authors do not claim they have found a complete explanation of the anomalies, but they think the results obtained are extremely interesting and very significant.

After considering the differences in the nature of Swedish Lancashire iron and Armco iron resulting from their respective processes of manufacture, the two outstanding features seemed to be that the former has substantial quantities of slag particles embedded in it, whilst the latter invariably contains an appreciable quantity of alumina in the form of tiny specks. It was thought that there would be comparatively little difficulty in freeing the former metal from slag during the melting operation, but it is well known that finely divided alumina is much more difficult to get rid of during melting. Be that as it may, on examining specimens under the microscope it was found that those made from Swedish

Lancashire iron contained much less non-metallic inclusions than the casts made from Armco iron; further, the inclusions in the latter seemed to correspond in form to particles of alumina. However, it was decided to introduce alumina intentionally to some further casts of low-copper samples in order to find whether the presence of this intentionally added inclusion in a finely divided form would increase the rate of acid attack upon cold-rolled specimens. With this in mind, the aim was to add a known quantity of oxide of iron to the metal during melting, and after allowing time for this to be dissolved, to introduce the theoretical amount of aluminium to reduce the oxide of iron.

Two such casts were made, one from equal quantities of Armco iron and Swedish Lancashire iron to give a copper content of 0·05%, and the other entirely from Swedish Lancashire iron to give a copper content of 0·005% (in both instances the sulphur was 0·10%). The same quantities of oxide of iron and aluminium were added to each, and therefore the amount of intentionally introduced alumina inclusions would presumably be the same. On the other hand, it may be supposed that the total quantity of alumina present would be greater in the specimen containing 0·05% of copper, because in this case half the original charge consisted of Armco iron.

When samples from these casts were subjected to attack in the cold-rolled condition by citric acid and the results were compared with those obtained from steels of similar composition but containing no additions of alumina, it was found that an increase in the rate of corrosion had occurred. On reference to Table XIX. and Fig. 23, it will be seen that the following values were obtained :

Sample No.	Copper. %.	Sulphur. %.	Loss of Weight. G.
18	0·005	0·087	0·2907
37 *	0·005	0·099	0·3261
20	0·05	0·099	0·1544
39 *	0·05	0·101	0·3899

* With added alumina.

It will be noticed that the amount of the increase of attack on sample No. 37 was not so great as that on No. 39; it is thought that this is due to the presence of a smaller quantity of alumina in the former; the reason for this has already been indicated.

In view of these results, it was decided to introduce alumina when making two further casts containing about 0·15% of sulphur and 0·05 and 0·005% of copper, respectively. The results obtained for cold-rolled specimens of these two samples have been incorporated in Fig. 23. These give a regular curve, indicating that with heavy cold-rolling, in a series containing about 0·15% of sulphur, the rate of attack steadily diminishes (in citric acid) as the copper is increased from 0·005 to about 0·14%.

Whilst the range of experimental work so far done concerning the influence of alumina is admittedly somewhat limited, the evi-

dence certainly seems to warrant the conclusion that cold-rolled specimens to which alumina has been added are more quickly attacked by a 2% solution of citric acid than corresponding specimens to which no such additions have been made. It now becomes a matter of some interest to examine whether the presence of alumina has any noticeable effect upon the rate of attack on samples in the annealed condition. The following data indicate that, under these conditions, the presence of alumina does not increase the rate of attack:

96 Hr. at 25° C.

Sample No.	Copper. %.	Sulphur. %.		Loss of Weight. G.
18	0·005	0·087	No alumina added	0·1286
37	0·005	0·099	Alumina added	0·0971
20	0·05	0·099	No alumina added	0·1012
39	0·05	0·101	Alumina added	0·0871

At this stage it seemed necessary to enquire whether alumina additions would have the same effects with sulphuric acid as had been observed with citric acid. With this in mind, a similar series of tests was made, using a 6% solution of sulphuric acid, with the following results:

24 Hr. at 25° C. Cold-Rolled.

Sample No.	Copper. %.	Sulphur. %.		Loss of Weight. G.
18	0·005	0·087		2·2904
37	0·005	0·099	With alumina	1·9621
20	0·05	0·099		1·1472
39	0·05	0·101	With alumina	1·8156

Corresponding samples in the annealed condition gave the following results:

Annealed.

Sample No.:	18.	37.	20.	39.
Loss of weight. G.	1·1304	1·1331	0·1760	0·1720

The results obtained with specimen No. 37 in the cold-rolled condition indicate that alumina is without influence, but with No. 39 there is a marked increase in the rate of attack. It will be remembered that in citric acid the influence of alumina was relatively not so pronounced in No. 37 as it was in No. 39. This rather negative result for No. 37 is thought to be partly accounted for by no Armco iron being used in the charge.

Whilst recognising that the evidence is incomplete, the authors are definitely of the opinion that the presence of non-metallic inclusions, such as alumina, cause an increase in the rate of acid attack on specimens in the cold-rolled condition. Quite apart from what has been found in this connection with regard to alumina, considerable support is lent to the above general conclusion by the fact that the presence of other undissolved constituents or inclusions,

such as carbide of iron and sulphide of manganese, give rise to an increased rate of acid attack after cold-rolling. With phosphorus, however, which dissolves in the ferrite, practically no difference between annealed and cold-rolled specimens can be detected (*see* Fig. 2 for the series containing phosphorus up to 0·14% and very low carbon and sulphur contents).

Quite a noticeable influence can be seen, however, when appreciable quantities of carbon are present. It is true that with carbon above, say, 0·02%, the ferrite itself contains more carbon in solution, and this difference might cause a difference in the rate of acid attack after cold-rolling, but the authors wish to point to the possibility of the observed effects being due to the mechanical influence of carbide of iron during cold-rolling.

Then with regard to sulphur, as the amount of this element increases, the effects of cold-rolling in increasing the rate of attack become more and more marked. This observation, however, must be qualified by the statement that the magnitude of the differences between annealed and cold-rolled specimens is reduced as the copper content increases, and become negligibly small when the copper is about 0·14%. Whether the increased copper content modifies the chemical character of the sulphide inclusions or simply changes the manner in which the ferrite undergoes plastic deformation at ordinary atmospheric temperature the authors cannot say. The fact remains that there seems to be an appreciable amount of evidence for the view that, under certain conditions, the presence of particles of such constituents as alumina, sulphide of manganese and carbide of iron, cause cold-rolling to leave the metal in a state in which it dissolves more rapidly in solutions of citric or sulphuric acid. If further work substantiates this possibility, then the authors think it might be explained on the grounds that the deformation of the ferrite during cold-rolling is unusually severe at and near the inclusion, leading to something in the nature of incipient internal rupture as it flows round the inclusion.

As a further step in the study of this aspect of the problem, the authors have examined the effects of annealing a series of cold-rolled specimens at varying temperatures upon the rates of acid attack. For this purpose, four samples containing approximately the same percentage of sulphur, namely, 0·15%, and 0·075, 0·115, 0·14 and 0·24% of copper, respectively, were selected. After cold-rolling in the usual manner, they were annealed at various temperatures up to 950° C., and the rates of acid attack were then determined. The results for sulphuric and citric acid solutions are given in Tables XX. and XXI., respectively, and are plotted in Figs. 24 and 25.

The data from the tests with sulphuric acid solution appear to stand out in bolder outline, especially when examined in the form of curves (*see* Fig. 24). This is, no doubt, largely due to the degree of attack being so much greater than when citric acid was used,

TABLE XX.—*Influence of Re-annealing the Cold-Rolled Samples on the Rate of Acid Attack.* 6% *Sulphuric Acid for* 96 *Hr. at* 25° *C.*

Sulphur content 0·15%.

Re-annealing Temperatures. ° C.	Loss of Weight. G. (Average of 3 Results.)			
	0·24% Cu.	0·14% Cu.	0·11% Cu.	0·075% Cu.
As-rolled . .	0·7564	0·9603	2·0353	2·2827
100 . . .	0·6863	0·8441	1·6762	1·9228
200 . . .	0·5532	0·6838	0·9235	1·1627
300 . . .	0·5290	0·6320	0·8534	0·9615
500 . . .	0·4762	0·5684	0·6372	0·7389
700 . . .	0·4068	0·5219	0·5647	0·6509
950 . . .	0·4114	0·4728	0·5843	0·6792

TABLE XXI.—*Influence of Re-annealing the Cold-Rolled Samples on the Rate of Acid Attack. Citric Acid for* 144 *Hr. at* 25° *C.*

Sulphur content 0·15%.

Re-annealing Temperatures. ° C.	Loss of Weight. G. (Average of 3 Results.)			
	0·24% Cu.	0·14% Cu.	0·11% Cu.	0·075% Cu.
As-rolled . .	0·1226	0·1349	0·2076	0·3167
100 . . .	0·1534	0·1548	0·2682	0·3687
200 . . .	0·1336	0·1600	0·1972	0·2054
300 . . .	0·1475	0·1585	0·1810	0·2099
400 . . .	0·0993	0·1058	0·1407	0·1365
500 . . .	0·1218	0·1092	0·1429	0·1394
700 . . .	0·1064	0·0967	0·0984	0·1306
950 . . .	0·1178	0·1322	0·1084	0·1153

and not because there is any really fundamental difference in the behaviour of the materials in the two acids. In other words, the forms of the curves for citric acid attack would probably become similar to those for sulphuric acid by extending the period of attack. On examining the curves in Fig. 24 it will be noticed how very much greater is the rate of attack with the specimens in the cold-rolled condition, as compared with the same material after annealing at 950° C. The difference in this respect is extraordinarily large for the specimens containing 0·075 and 0·11% of copper, but very considerably less for those containing 0·14 and 0·24% of copper. Further, as will be seen from the curves, the effects of cold-rolling are to a substantial extent removed by annealing at 200° C., but this is not complete until an annealing temperature of something over 500° C. has been reached.

The authors are not able to give a complete explanation of these

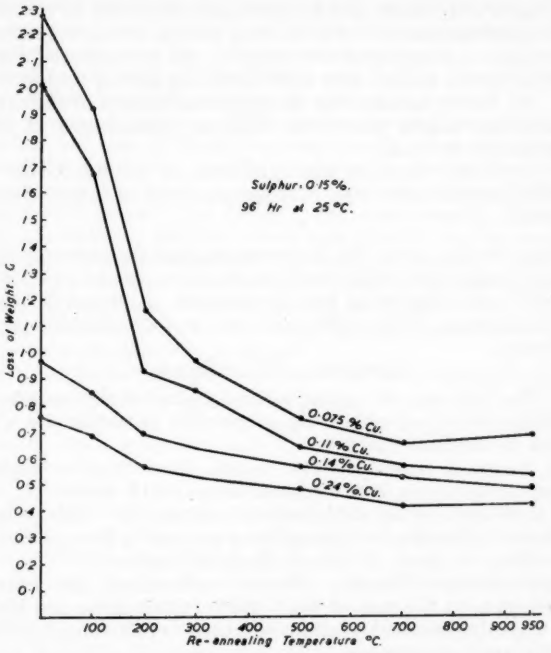

FIG. 24.—Influence of Re-annealing Cold-Rolled Specimens, 0·15% of sulphur; 6% sulphuric acid, 96 hr. at 25° C.

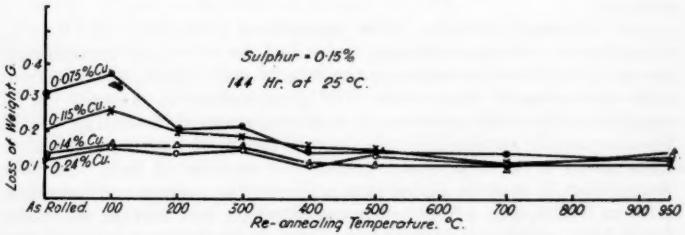

FIG. 25.—Influence of Re-annealing Cold-Rolled Specimens, 0·15% of sulphur; 2% citric acid, 144 hr. at 25° C.

results, but they feel that the following observations are worthy of consideration, and might form the basis of further work:

They may be accounted for—

(*a*) Partly along the lines already discussed in relation to the possible influence of inclusions, such as alumina, manganese sulphide and carbide of iron, &c. (*i.e.*, the excessive deformation of the ferrite at and near such inclusions during cold-working).

(*b*) Partly because the chemical constitution of the sulphide inclusions might vary with differing percentages of copper present in the steel.

(*c*) Partly because the behaviour of ferrite during cold-rolling might differ with varying quantities of copper dissolved in it.

Whatever the cause, the fact remains that the presence of, say, 0·25% of copper very considerably reduces the rate at which heavily cold-rolled steel containing high percentages of sulphur is dissolved in acid solutions. This might prove to be of considerable practical significance.

Summary of Conclusions.

(1) The influence of varying percentages of phosphorus in steels containing 0·02% of carbon upon the rate of attack by a 6·0% solution of sulphuric acid :

(*a*) *Annealed Samples.*—The results show that a progressive increase in the phosphorus content from 0·014 to 0·124% brings about a steady increase in the rate of acid attack. This causes the rate at the higher limit of phosphorus content to be approximately twelve times as great as that at the lower limit.

(*b*) *Cold-Rolled Samples.*—Heavy cold-rolling has extremely little effect upon the rate at which steels in this group are dissolved in a 6·0% sulphuric acid solution, but, there is just a slight indication that it causes an increase.

(2) The influence of phosphorus in the presence of increasing percentages of carbon upon the rate of attack in a sulphuric acid solution :

(*a*) *Annealed Samples.*—The presence of 0·08, 0·115 and 0·15% of carbon in steels containing from 0·01 to 0·12% of phosphorus causes a definite retardation in the rate of acid attack, as compared with the series in which only 0·02% of carbon is present. It is considered that this influence is due to a protective coating which forms upon the surfaces of the specimen during the action and which consists of a decomposition product of carbide of iron. In this connection, it may be noted that a rise in the carbon content from 0·02 to 0·08% has a very pronounced effect, but further increases have little additional influence. These facts clearly emphasize the need for caution when drawing conclusions concerning the influence of elements, other than carbon, upon the rate of attack when the carbon content in different samples varies much between 0·02 and 0·08%. In this connection, it should be especially remembered that surface variations in the carbon content of even greater magnitude can be brought about during commercial annealing operations.

(*b*) *Cold-Rolled Samples.*—Cold-rolling causes the rate of attack to be increased, and the tendency in this direction appears to become somewhat greater as the carbon content is raised.

(3) The influence of phosphorus and carbon in steel upon the rate of attack in a 2·0% solution of citric acid :

(*a*) *Annealed Samples.*—With specimens containing only 0·02% of carbon, the rate of attack increases rapidly when the phosphorus is raised from 0·014 to 0·048%, and this tendency continues, but rather less quickly, as the phosphorus is further increased to 0·124%. When 0·08% of carbon is present, the same general observations apply, phosphorus between 0·048 and 0·124% having much less effect than in the presence of only 0·02% of carbon. With 0·115 and 0·15% of carbon, much the same effect is produced by raising the phosphorus from 0·014 to 0·048% as in those specimens containing less carbon, but by increasing the phosphorus above 0·048% no greater acid attack is produced.

(*b*) *Cold-Rolled Samples.*—The effect of cold-rolling is to cause a slight increase in the rate of acid attack.

(4) The influence of varying the percentages of sulphur and copper in steels upon the rate of attack by solutions of sulphuric and citric acid :

(*a*) *Annealed Samples.*—With the range of samples that have been examined in the present investigation, it has been found that :

(i) With any given series containing a constant percentage of copper, variations of sulphur up to 0·15% have very little effect upon the rate of acid attack (*see* Fig. 13). This general statement is, however, only true provided that the copper content is above, say, 0·05%. With a very low percentage of copper—say, of the order of 0·005%—increases in the sulphur content up to 0·15% give rise to remarkably large increases in the rate at which the steel dissolves in sulphuric acid (*see* Fig. 16), but, this is not nearly so clearly defined with citric acid (*see* Fig. 19).

(ii) For any given percentage of sulphur, increasing the copper above 0·005% has a marked retarding effect on the rate of attack. This is very rapid on raising the copper from 0·005 to 0·05%, and proceeds at a diminishing rate with increases of copper up to about 0·115%. Further increases above the latter figure have no appreciable influence (*see* Figs. 16 and 19). All the evidence seems to indicate that there is a critical percentage of copper which brings about the maximum degree of retardation in the rate of acid attack, and this critical figure, which is about 0·115%, appears to be independent of the sulphur content. Special attention should be drawn to the fact that, in considering the influence of a given element upon the rate of acid attack, care must be taken to see that the degree of attack is sufficient. This applies particularly to copper (*see* Figs. 17 and 19, where it will be observed that pronounced attack is necessary before clearly defined curves are obtained).

(*b*) *Cold-Rolled Samples.*—The effect of heavy cold-rolling is to

increase the rate of acid attack. The tendency in this direction increases, on the one hand, as the percentage of sulphur is raised, and, on the other, as the copper content decreases.

(5) There are definite indications that the presence of inclusions, such as alumina, manganese sulphide and carbide of iron, give rise to an increased rate of attack by acids after steel has been cold-rolled. With phosphorus, which dissolves in ferrite, practically no difference between annealed and cold-rolled specimens can be detected in this respect.

Acknowledgments.

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The authors wish to thank Messrs. Baldwins, Ltd., for having kindly arranged to have the cast bars rolled in their works.

They also wish to acknowledge the valuable assistance that they have received from time to time during the investigation from Messrs. C. E. Beynon, B.Sc., C. J. Leadbeater, M.Sc., and W. Davies, B.Sc., who acted as assistants during certain stages of the work.

DISCUSSION.

Mr. J. H. Whiteley (Consett, Co. Durham) said that he had read and considered this paper very thoroughly, for he need hardly say that any paper with which the name of Principal Edwards was associated demanded the closest attention. The amount of tedious work involved in the present investigation must have been very great, and he thought that the patience and perseverance displayed should not pass unnoticed.

His first remarks related to Tables I. and II., which were the only ones of their kind presented, and, moreover, the authors had but partially dealt with them. Apart from the effect of phosphorus, perhaps the most striking fact they revealed was that the rate of attack in 6% sulphuric acid increased with time notwithstanding the diminishing acid strength. Until the loss in weight was about 0·1 g. the rate was relatively slow at all temperatures, and thereafter a definite acceleration was evident. Now, in considering this feature, it occurred to him that there might be here some connection with the primary crystallisation in the ingot, for, in the method used for casting, it was to be expected that the crystallites formed at the skin would be extremely fine and would grow progressively larger inwards. Unfortunately, no illustrations of the ingot structure or of any of the samples used were given, but it seemed reasonable to infer that the crystals would grow in this manner. Thus, what might be termed the texture of the rolled steel would change somewhat from the outside to the centre, and it seemed possible that this variation was responsible for the acceleration in the rate of attack. If this explanation was anywhere near the mark, it might also account for the effect produced by phosphorus, since that element widened the temperature range between the liquidus and solidus and so probably altered appreciably the macrostructure of the ingot in regard to the extent of interdendritic segegration. In this connection it would be worth while, he thought, to make an ingot in the same way, roll it into a plate, say, $\frac{1}{4}$ in. thick, and then compare its rate of solution with that of the same material in much thinner form.

His second point with respect to Tables I. and II. referred to the authors' statement that they showed "a general indication that cold-rolling causes a slight acceleration in the rate of attack." On examining the figures carefully he failed to see this general indication, and finally satisfied himself that it was not there by adding together the five figures in each block. Thus the total for sample No. 1 annealed after 1-hr. immersion was 0·3424 g., and in the cold-rolled state it is only 0·2761 g. Similar differences were given by all the samples, both for the 1-hr. and 2-hr. treatments. Even after 4 hr. sample No. 3, annealed, was still lower, and it was only after 22 hr. that the acceleration of attack due to cold-rolling became really apparent. Therefore, he was not sure that the authors were justified in selecting

the 22-hr. results as an illustration of the effect of cold-work, as was done in Fig. 2, no matter what any other evidence might indicate.

The next thing he wished to consider was the effect of alumina inclusions which the authors had invoked to explain a perturbingly inconsistent result which appeared. On p. 255 four results were given which seemed to indicate that the presence of alumina particles in cold-rolled steel caused an acceleration of the rate of attack by citric acid. Now, on p. 256 the results given by the same steels in the annealed condition under the same treatment were presented, and it would be seen that the state of affairs was almost completely reversed. Thus, when cold-rolled, sample No. 37 lost 0·0354 g. more than No. 18, and when annealed it lost 0·0315 g. less. Differences of the same kind were also evident between the figures for samples 20 and 39. As these facts could not have escaped the authors' attention, one wondered why they had not been mentioned.

The authors' statement that Armco iron " invariably contains an appreciable quantity of alumina particles in the form of tiny specks " came as a surprise, for he had examined, from time to time, many different samples of this material and had always found the numerous small inclusions present in it to consist almost entirely of FeO. They were about the usual size of alumina inclusions, but differed in that they were readily soluble in very weak acids and were easily reduced by hydrogen at 900° C. Moreover, they formed the characteristic FeO–FeS eutectic, which could usually be observed in the specimens on close examination. It was possible, of course, that in the particular Armco iron used by the authors the inclusions were of the kind they stated. If so, then surely the quantity present could have been given, not only in that material but also in samples 37 to 40, for alumina was an easily estimated substance in steel; indeed this fact has been made use of in the attempt to find a ready means of estimating oxygen in steel. He would therefore suggest that the authors re-examine these inclusions so as to place the matter beyond doubt. But even if they should discover that the inclusions consisted chiefly of FeO, as he rather expected, the theory advanced in the paper would not necessarily come to grief. Although not so hard as alumina, FeO particles were by no means soft, and so they might still give rise to the incipient internal rupture effects in cold-rolling which the authors had visualised as occurring with alumina inclusions. After considering the facts of the case as presented in the paper, he personally doubted very much whether inclusions had any real importance in influencing the rate of attack, for the results given were far from convincing. Other possibilities suggested themselves. For instance, was the Armco iron used throughout made from the same cast? If not, then there might be other variables to take into account, such as the arsenic content, of which no mention was made in the paper.

Finally, he would remark that when steel was cold-worked it

absorbed a certain amount of energy. That, he believed, had recently been definitely proved. The old question might, therefore, again be asked as to what became of this energy when the steel was dissolved in acid. Was it entirely liberated as heat, or did it also in some way activate the ions. Years ago, he had found, in collaboration with Dr. Hallimond, that when cold-worked iron was dissolved in hot nitric acid the course of the reactions was profoundly altered, and there was therefore a possibility that comparable changes might be produced in other acids. If, for instance, some oxidised substance reducible in successive steps could be added in excess to the solution, the relative quantities of the two or more reduced states might be found to vary according to the degree of cold-working applied to the metal. Unfortunately at the moment he was unable to suggest such a substance, but, nevertheless, the idea seemed to him to be worthy of some consideration.

Dr. T. P. Hoar (Cambridge) said he had been looking forward to the publication of the present paper for some time. He had been led to understand, by some remarks which Principal Edwards had made about a contribution of his own (with Mr. Havenhand) on a related subject, that the results which were now presented were in direct conflict with those which he had obtained. He was glad to find, on studying the paper, that that was not the case. The crux of the matter was that, whereas he and his collaborator were concerned with tinplate steels as one found them in practice, the authors had been more interested in specially made steels, many of which, as they themselves pointed out, would be useless for ordinary tinplate.

In that connection, he regarded the authors' method of preparing small amounts of material as chill-cast bars, and subjecting their pack-rolled sheets to no less than 100% cold reduction as ingenious, but rather remote from reality. He would have thought that it would have been of more immediate practical interest to have materials which were prepared in a manner similar to that used in tinplate practice. None of the present materials had been prepared by methods similar to those used in ordinary tinplate manufacture, and only No. 10 had a composition within the usual range of British tinplate.

Nevertheless, he thought that the results were of great fundamental interest, and that led him to certain questions and criticisms with regard to some of the experimental methods used.

First, he would like to ask where the analyses were taken. Were they taken from the cast bars or from the rolled sheets? He thought that the sheet analysis would be the more interesting. Secondly, the authors gave only the barest description of their corrosion vessels, and made no mention of the degree of temperature control achieved; but, since the geometry of the corroding system and its temperature very often had marked influences on the rate of attack, it was

important that such matters should have close attention and be reported. Thirdly, the authors' method of surface preparation of their sheets consisted of cold-rolling, close-annealing, cooling in town gas and degreasing. Specimens prepared in that way might well possess considerably different invisible oxide-films; some method of regular abrasion or pickling would have been preferable. In that connection, he noted that the reproducibility of the results obtained by the authors, as given on p. 228, was no better than that which he had obtained from ordinary tinplate materials prepared by regular abrasion, although the authors' materials were said to be very nearly homogeneous in composition.

He had one other, more serious, experimental criticism. It referred to the results in citric acid at 75° C. shown in Figs. 8, 9, 10, 11 and 19; 250 c.c. of 2% citric acid were used, *i.e.*, 5 g. of citric acid, which was equivalent chemically to 2 g. of ferrous iron. But in the figures to which he had referred many of the points illustrated the corrosion of from 1 to 1·5 g. of iron, *i.e.*, over half of the original acid had been used up during corrosion, and the steel for a great part of the experiment was corroding, not in citric acid, but in a slightly acid solution of ferrous ferrocitrate. Thus the higher points on the curves were not comparable with the lower ones.

Apart from those criticisms, he thought that the results were very interesting. The authors had shown that the accelerating influence of phosphorus in nearly pure iron was greatly modified by the addition of carbon to the pure iron, and it seemed to him that the influence of phosphorus might be quite different in a steel of ordinary tinplate composition with average amounts of sulphur, copper, &c., as well as of carbon, in the steel. The same point applied to the experiments on sulphur. They showed that sulphur was an accelerating factor only in steels in the cold-rolled condition, and not in the annealed condition; but, as in the case of phosphorus, the steels were very low in elements other than sulphur—*e.g.*, in carbon and phosphorus. Again it seemed possible that if steels were made which contained *average* amounts of the other impurities, the effect of sulphur might be different from that which the authors had found in their materials.

It was interesting to see that in the case of copper the authors came to much the same main conclusion as that which he and Havenhand had reached for commercial tinplate steel base, namely, that copper was a very potent retarder of the attack of mild steel by acids. He did not think, however, that the break which the authors suggested in the curve of copper content against corrosion rate (at 0·115% of copper) was significant, and he considered that the results could be still better expressed by smooth curves. The matter could be tested by a statistical analysis of the regression of the corrosion rate with increasing copper content.

The authors suggested that the protective influence of carbon in their phosphorus series was due to the formation of a layer of

decomposed cementite on the surface of the metal. He had never, in the course of the examination of a large number of tinplate materials, come across such a layer, and he would like the authors to give their evidence for it in more detail. Also, he regretted that no photomicrographs were included to show the distribution of the cementite in the materials. It was at least possible that the *higher*-carbon materials actually contained *less* massive cementite than the low-carbon ones, and therefore an accelerating influence of massive cementite was shown in the low-carbon steels more than in the higher-carbon steels.

The results with regard to cold-rolling were most interesting, and the tentative explanation was very attractive. In that connection, it would perhaps be interesting to discover whether the anodic or the cathodic corrosion process was stimulated by cold-rolling, by means of electrode-potential measurements.

Summing up, he would say that the results were of very great interest to the fundamental or academic corrosion worker, but of no immediate practical importance to the consumer or manufacturer of tinplate. If the authors would make castings of these small amounts of materials more nearly resembling the practical steel, if they would roll and anneal such castings in ways similar to those employed in practice, and if they would arrange to have the composition of the final sheets a reasonable average for steel base, then the results of carefully controlled corrosion tests in weak acid media, to be followed by practical canning tests of tinplates made from the materials, would be of the highest value to those interested in commercial tinplate. But, until that could be done, he was confident that statistical researches on commercial tinplate, properly arranged and analysed, had more practical value; for they gave results which could safely be said to apply to *average* tinplate, which the authors' present experiments did not.

Dr. U. R. Evans (Cambridge) said that there were two aspects of the interesting paper which the authors had presented: (1) The *pure science* aspect, the contribution to our actual knowledge of the hydrogen evolution type of corrosion of iron and the effect of minor constituents on that type of attack, and (2) the possible bearing of the results on *industrial* problems connected with tinplate.

With regard to the *pure science* aspect, the paper was very much to be welcomed. There was, of course, a certain amount of information already available on the effect of the various minor constituents on corrosion by acids; apart from the papers mentioned by the authors, there was some work by Endo in Japan. Knowledge of the matter, however, was sadly incomplete, and he was sure that all those interested would be very glad to have the material which the authors presented, which made their knowledge much more complete.

He had only a few minor criticisms to make. The specimens

(including the annealed specimens) were bent before the corrosion. Almost all those who had studied the subject had reached the conclusion that bending greatly influenced, and generally accelerated, the rate of attack by acids (the effect of bending on corrosion by neutral solutions was very much smaller, and often inappreciable). It would seem important, therefore, to know the manner of bending and the radius of curvature, and possibly that information could be provided; in any case, he felt sure that the bending would be controlled carefully in any future work.

Again, the specimens were placed in a flask, and a certain volume of acid was added. It was important to know the dimensions of the flask, which of course would determine the depth of immersion—a factor of some importance, at any rate in the case of dilute acid solutions, because replenishment depended very much on the rising of hydrogen bubbles and the drawing-in of fresh acid below. For the weaker acids the introduction of oxygen by means of those bubbles might affect the results, and this would also be affected by the size of the flask and the exact position of the specimens in it. In addition, a rather important point was the exact shape of the flask bottom. With a round bottom the replenishment of acid would be different from that which took place with a bottom of a re-entrant form. However, those were merely small points of criticism, and did not affect the general conclusions.

Coming to the *industrial* side of the matter, he felt a little uncertainty. He was not quite sure whether 22 hr. in 6% sulphuric acid was supposed to represent a year or so in fruit juice. It was quite possible that it would produce as advanced a stage of corrosion, but he felt that it would be corrosion of a somewhat different type, and that it might be affected differently by various minor constituents. It must be remembered that the sort of constituents which accelerated corrosion in 6% sulphuric acid would be those which introduced a large number of points of *medium* over-potential, whereas for slow corrosion in weakly acid liquids like fruit syrup they would probably be those which conferred a limited number of points of *very low* over-potential; the two things might not go together. Consequently while it might be right to start with tests in 6% sulphuric acid, it would probably be necessary to proceed later to tests closer to service conditions.

It must be remembered that the iron was never exposed in the bare state to fruit juice; the greater part of the surface was covered up by tin. There were always some points, however, which the tin for some reason had failed to wet, and these were exposed to the fruit juice. The question arose as to whether the steel which was exposed at these pin-holes was the same as the steel everywhere else. He thought that it must be different, since otherwise the tin would not have refused to wet these spots. The "ideal" research would be carried out on samples representing the composition of the untinned spots, although they would not be easy to obtain.

Furthermore, the corrosion of cannisters was not simply a case of direct attack on the steel exposed at the pin-holes. There was, he thought, no doubt that electrochemical couple-action occurred between the tin coating and the exposed steel. In most fruit juices the tin was anodic and afforded a certain measure of cathodic protection to the steel exposed; in certain other media, the tin was cathodic and the steel anodic, and then there would be localised attack.

If minor constituents were added to the steel, it was important to know how they distributed themselves between the main body of the steel and the exposed points, and in particular how they affected the polarity of the exposed parts. If they made the steel there more cathodic, they would certainly reduce the rate of attack to a large extent; but if they made it less cathodic, and possibly even anodic, they would be injurious from the point of view of canning. He did not think that very much information about electrical polarity was obtainable directly from immersion tests in sulphuric acid, or even in citric acid; he thought that electrochemical tests were also required, carried out (he hoped) at University College, Swansea, or, if that was not practicable, by arrangement with some other laboratory. It was possible that this electrochemical work was already being carried out, or at any rate being planned. If it was in progress, he would like to express the hope that the results would be published as soon as was reasonably possible, because they would be extremely interesting to industrialists and scientists. If it was being planned, he would ask the authors very earnestly to make a very careful study of the electrochemical factors involved, which were more complicated and, if he might say so, more difficult than was sometimes appreciated. While the experimental study of electrochemical phenomena without electrochemical measurements was to be regretted, electrochemical measurements were worse than useless if made without a full consideration of the scientific factors involved.

Mr. T. N. Morris (Cambridge) said that there was not a great deal that he could add to what previous speakers had said, but he would like to endorse in particular what Dr. Hoar had said, because his own experience had been similar in many respects.

He was particularly interested in the statement about the variation of the rates of corrosion of different specimens cut from the same sheet. His own experience with regard to the variation between different emery-treated specimens was that some mild-steel sheets gave reasonable agreement as between specimens cut from different parts, whilst others did not. He obtained for his work, largely through the kindness of Principal Edwards, sheets from a number of factories in the Swansea area and found that on the whole not only did specimens cut from the same sheets agree very well, but also there was good agreement between different sheets from the

same factory. With regard to sheets from different factories, there were differences, but they were relatively small. That applied to materials from the South Wales area. In the case of imported steel sheets, there were very considerable differences between specimens cut from the middle regions and from near the edges. In 0·5% citric acid solutions at 25° C. those from the middle regions sometimes corroded twice as fast as others from near the edges. With the Welsh steel, however, as he had already said, there was very little difference between the edges and the middle, and if anything the edges corroded a little faster than the centres. He made that statement because Principal Edwards might possibly know of differences in the methods employed in Britain and abroad which might account for those differences between the edges and the middle regions.

Dr. J. C. HUDSON (Birmingham) remarked that the work described in the paper was of great interest to his colleague, Dr. Banfield, and himself, because they were engaged in somewhat similar work in connection with their investigations for the Corrosion Committee. They had approached the problem from a rather different angle, because they were primarily concerned with the use of sulphuric acid solutions for removing the rust from corroded specimens; for this purpose they added an inhibitor to the solution. At a very early stage in their use of that method, they had found that even in the presence of an inhibitor the rate of dissolution of the metal base, which naturally they wished to prevent entirely, varied considerably from one material to another, and in the end it had become necessary to undertake a systematic laboratory investigation of the effect of acid solutions on the different wrought irons and steels under test by the Corrosion Committee. Although the compositions of these materials did not vary in the same way as those of the materials used by the present authors, he thought that the results of the work would be of interest to them and to others who were engaged in studying the dissolution of ferrous materials in acid solutions, because as a preliminary step Dr. Banfield and he had set out to investigate the influence of various experimental factors on the results obtained, as distinct from the composition of the materials.

These preliminary results had been published in the Fifth Report of the Corrosion Committee (pp. 279–292) and had thrown considerable light on the effect of such experimental variables as the size of specimen, the time of immersion, the temperature and concentration of the sulphuric acid solution, &c., on the rate of dissolution of ordinary mild steel. Since the authors referred on pp. 228 and 229 to marked anomalies in the attack on apparently similar specimens, he thought it would be of interest to refer briefly to some of the results obtained in his own work with Dr. Banfield, which illustrated the pronounced effects of segregation, to which the authors had referred, and of surface condition, on the results obtained.

In their tests, his colleague and he had measured the rate of hydrogen evolution from ordinary mild steel with a carbon content of about 0·2%, which was rather higher than those of the materials used by the authors. The concentration of the sulphuric acid solution, 7·5*N*, was also greater, but otherwise the experimental conditions appeared to be roughly comparable. Their experiments showed, as was clear from the curves reproduced in Fig. A, that in the initial stages of attack the rate of hydrogen evolution varied very considerably with the surface condition of the steel. When

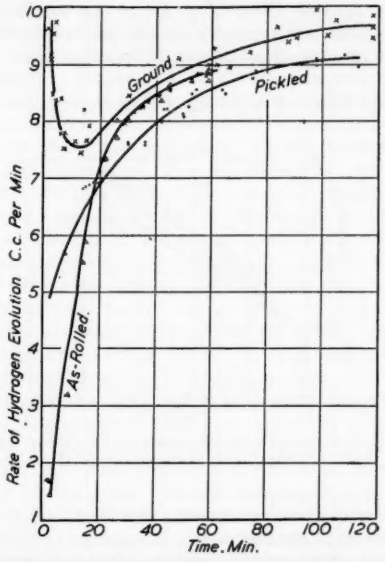

FIG. A.—Effect of Surface Condition on the Rate of Hydrogen Evolution (7·5*N* "puriss." sulphuric acid, 40° C.).

the specimens were tested in the as-rolled condition, with the rolling scale left on, the rate of attack at first was almost nil, as might have been expected, but it would also be noted that there was a marked difference in the behaviours of pickled and ground surfaces, the initial rate of attack on the latter being relatively very much greater.

The specimens used were sawn from 2 × $\frac{1}{8}$-in. strip, with the result that the total surface exposed to the acid included both the original rolled surface, or its equivalent after descaling, and two cross-sections of the strip, which exposed any segregates in the less pure core. (The mild steel tested was rolled from an ingot showing a slight rim). They had studied the effect of exposing the core, as

distinct from the flats, by conducting experiments on specimens of different lengths, thus varying the area of the flat surfaces while the area of cross-section remained constant. The results obtained were shown in Fig. B. It would be seen that linear relationships were observed between the rates of dissolution and the length of the specimen, from which it could be deduced that, under the experimental conditions prevailing in their experiments, the rates of dissolution of mild steel from pickled, as-rolled, ground and sawn (transverse) surfaces were in the ratio of 1 : 1·11 : 1·33 : 4·5.[1] Hence the rate of dissolution from the cross-section of the strip was 4·5 times greater than that from the surface itself, which confirmed the authors' remarks as to the marked effect of any segregation or of any irregularity in composition on the results obtained.

Actually, the effect of exposing the cross-section of the material

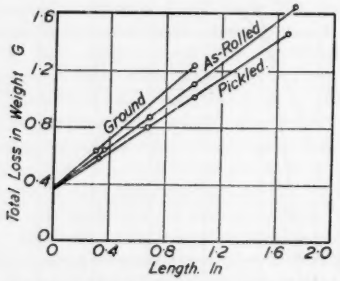

FIG. B.—Effect of Length of Specimen on the Total Loss in Weight (7·5*N* "puriss." sulphuric acid, 40° C., 1 hr.).

would be greater in the experiments to which he had alluded and in which the transverse area exposed was about 11% of the total area of the specimen than in the work of the authors, for which the corresponding figure was 3%. In this connection, he would point out that the probable experimental error of the results for the three inside specimens that had been wrapped in sheets of the same material during annealing, as given by the authors on p. 228, was

[1] It should be noted that the steel was pickled or ground in fairly large pieces and that the specimens themselves were sawn off after the descaling treatment. An exact comparison between the rates of dissolution of the flat and transverse surfaces respectively could only be made if both surfaces were prepared in the same surface condition, *i.e.*, if, in the present instance, the flats had also been prepared by sawing. Since, however, the rates of dissolution from flat surfaces prepared by pickling and grinding respectively were in the ratio of 1 : 1·33, it was probably fair to conclude that the much greater difference between the transverse section and the flats observed in these experiments was due to the exposure of the less pure core of the material.

2·5%, as compared with an average figure of 0·9% for all the experiments in the work he had described. He did not make this comparison in any critical spirit (in his own work with Dr. Banfield very much greater probable experimental errors had been observed in, as yet, unpublished work on other materials, such as wrought iron, in which the surface preparation might result in the irregular exposure of segregates, as between one specimen and another), but merely in support of the view, which the authors appeared to hold, that the difficulty of obtaining perfectly comparable specimens had not been entirely overcome and was a matter requiring further study (*cf.* p. 229).

It was desirable that the authors should define the sulphuric acid used in their tests more exactly, in regard to both quality and concentration. Regarding the latter, it was not quite clear whether their solution was 6% by weight or by volume, although presumably the former was implied; to avoid ambiguity it would be preferable to state the normality of the solution. So far as acid quality was concerned, it was necessary, for very accurate laboratory work such as that of the authors, to be very careful in the choice of the acid used. Dr. Banfield and he had investigated the effect of acid quality on the rate of dissolution. They had found that the rate of dissolution of ordinary mild steel in sulphuric acid of " A.R." quality was considerably greater than the rate of dissolution in commercial acid. Comparable figures obtained under standard conditions were 1·063 g. per hr. for a 7·5*N* solution prepared from " A.R." acid and 0·881 g. per hr. for a similar solution prepared from commercial acid (*loc. cit.* Table CL., p. 289). The difference thus amounted to as much as 20%, and was in accordance with the observations of practical picklers that the descaling of steel took place more sluggishly in some acid baths than in others of the same concentration. The rate of dissolution was probably connected with the arsenic content of the acid. In the experiments to which he had referred, the " A.R." acid was found to contain less than 0·1 part of arsenic per million, whereas the commercial acid contained about 1·3 parts; the arsenic acted as an inhibitor of corrosion.

With regard to the main features of the authors' work, the effects of differences in composition on the rate of dissolution of the steels, he thought that the results obtained were extremely valuable and interesting; so far as his limited knowledge went, he was in general agreement with the conclusions reached by them. The value of the authors' work was materially enhanced by the fact that it had been conducted under well-defined conditions, and in particular by the fact that they had made all experiments in triplicate. Although this must have added considerably to the work, the additional labour had proved well worth while, and it was in the general interest that, when experiments such as these were undertaken, they should be done as thoroughly as in the present case. There could be general confidence in the results obtained by the authors,

and he hoped that they would be able to extend their work to the consideration of the effects of other elements.

Mr. J. S. LEWIS (Briton Ferry, Glam.) congratulated the authors on bringing forward again a subject which was of such vital importance and one in which users of mild-steel sheets and tinplate took such a keen interest. In the present stage they had, in his opinion quite rightly, started from what might be termed fundamentals. They had investigated the influence of carbon, phosphorus, sulphur and copper in the main, and, having carried out their investigation, if the matter was carried further they knew what to look for. He thought that they had been very wise in adopting that view.

The paper was really a statement of facts; the authors had carried out their investigation and put their results forward for consideration, and it was up to every reader of the paper to draw his own conclusions, which might or might not agree with those to which the authors had come. He would like to disagree to some extent with their conclusion, if one might call it so, on p. 231, where they said : " It is true, however, that there is a general indication that cold-rolling causes a slight acceleration in the rate "—he agreed there—" but, in the absence of any other evidence, the differences could be regarded as being within the range of experimental error." There, he suggested, the authors showed to some extent a lack of confidence in themselves. They presented Fig. 2, which showed the influence of the annealed condition and the cold-rolled condition. The lines were almost parallel, and he suggested that the authors were really too modest in suggesting that such a consistent difference was an experimental error. They should have more confidence in themselves, and say definitely that that slight difference was due to the influence of cold-rolling.

He had been particularly interested in the results put forward with regard to the influence of copper and sulphur, and to his mind it was to some extent startling that, judging by such illustrations as Fig. 14 and Fig. 16, sulphur did not seem to have any appreciable effect—one might even go so far as to say that it had no effect—provided that a little copper was present. In Figs. 14 and 16 the authors put forward sulphur contents ranging from 0·02 up to 0·15%, with copper contents from 0·08 to 0·24%, and the whole of the series, from 0·021% of sulphur up to 0·15%, were almost coincident. Again with regard to the influence of copper and sulphur, and judging it purely from the results as put forward by the authors, who had been very patient and careful in their investigations, he had been surprised to find such a loose statement as that on p. 260, where the authors said : " Whatever the cause, the fact remains that the presence of, say "—it seemed a haphazard way of putting it—" 0·25% of copper " and so on. He would suggest to the authors that that figure of 0·25%, in view of their own results, was rather too high, and that the figure should be 0·115%. On the next

page they said : " For any given percentage of sulphur, increasing the copper above 0·005% has a marked retarding effect on the rate of attack. This is very rapid on raising the copper from 0·005 to 0·05%, and proceeds at a diminishing rate with increases of copper up to about 0·115%." There he thought that they were correct, judging the matter from their own results.

He had been particularly interested also in the remarks of a previous speaker, who seemed to look at the matter from the point of view of the user of tinplate. As one who was directly connected with the Welsh steel and tinplate trade, personally he had been very gratified to hear that from experience, and apparently from tests conducted, Mr. Morris had found that Welsh tinplate seemed to be more regular with regard to resistance to corrosion than tinplate which had been manufactured from imported steel. That was particularly gratifying to those connected with the industry in South Wales, because it was their endeavour to continue researches such as the authors of the present paper had carried out in order to improve even further the product which they sold. Mr. Morris asked whether the authors could give some explanation of that difference between tinplate made from Welsh steel and that made from imported steel. Personally, he would not presume to anticipate the reply of the authors, but he would like to suggest that the difference might be due to the difference in the method of manufacture of the steel base. Abroad, the main method of manufacturing mild steel for tinplate was the Bessemer process, the ingots being of the true rimming type, while in Britain, and in South Wales in particular, most of the steel for tinplates—in South Wales one might almost say 100%—was made by the open-hearth process, the steel being of the effervescing type. He suggested that that might be one of the reasons for the superiority of the home-produced tinplate over that made from imported steel.

Before concluding, he would like to thank the authors for bringing the subject forward again, and to express the hope that they would continue their studies further, and if possible from the commercial aspect. The authors were well aware that the tinplate and steel manufacturers of South Wales welcomed such a paper and promised every co-operation in the furtherance of knowledge on the subject.

CORRESPONDENCE.

Mr. W. E. Rhodes (Research Laboratories, Messrs. Chivers & Sons, Ltd., Histon, Cambridge) wrote that he felt privileged to have been present at the discussion of a paper which described so detailed a study of the influence of composition on the rate of acid attack on mild steel. As a member of the fruit canning industry, he was interested to learn that the investigations were to

be continued with materials of a composition more nearly approaching that of the steel base of tinplate. Such work might eventually lead to the solution of the hydrogen swell problem in canned fruits, which was undoubtedly a real one.

Under present conditions it was possible to select a uniform batch of fruit and pack it into cans which were passed through the canning process under conditions for all practical purposes identical, yet the subsequent storage life of the individual cans could vary very greatly. In the writer's experience it was common for some cans in such a batch to retain their original vacuum and for others stored for the same period and under the same conditions to develop a considerable internal pressure (perhaps 20 in.), owing to the formation of hydrogen by interaction between the can and its contents.

This variability was probably related to differences in the rate of acid attack of mild-steel samples under laboratory conditions such as were described in the authors' paper. The nature of the relationship should be more apparent when investigations were extended to cover material comparable with the steel base of tinplate.

In this connection also it was interesting to hear Dr. Evans' suggestion that fruit juices might provide the most suitable corrosion media for future work on the more practical aspect of the problem. As a result of work carried out in the writer's laboratory during the past few years, an attempt had been made to relate the rate of corrosion of a mild-steel base in 2% solutions of citric acid and in fruit juices to the storage life of fruit packed in cans manufactured from such baseplate. It had been found that a closer correlation was obtainable when fruit juices rather than citric acid solutions were used as the laboratory corrosion media. It was hoped to publish the result of the investigations in the near future.

In conclusion he felt that the problem covered a very wide field and could best be attacked by the joint efforts of tinplate research workers, research stations connected with the canning industry and the actual canners of food products.

Professor A. PORTEVIN (Paris) wrote that this paper as a whole represented one of the most important contributions in a very complicated field of research.

In studies which he had carried out with Dr. E. Herzog in the laboratories of the Aciéries de Pompey, he had obtained results comparable with those of the authors concerning the influence of small quantities of phosphorus on the speed of solution of dead mild copper steel in sulphuric acid. These steels were prepared in the induction furnace, cast in a metal mould, forged and rolled, and finally reheated in a manner similar to those examined by the authors. The losses of weight of these steels in sulphuric acid (30% by weight) as a function of the phosphorus content were given in Table A. The activating effect of this element (*see* Fig. 2),

almost proportional to the rate of solution between 0·014 and 0·120% of phosphorus, was observed both in his tests and in those of the authors. The only difference was that his steels contained copper.

TABLE A.

Analysis.						Loss in Weight in 30% H_2SO_4 at 30° C. G. per sq. m.	
C. %.	Mn. %.	S. %.	P. %.	Cu. %.	Si. %.	24 Hr.	48 Hr.
Steels made in Acid-Lined Induction Furnace.							
0·05	0·28	0·008	0·012	0·45	0·06	...	160–180
0·07	0·30	0·014	0·044	0·37	0·05	...	490–505
0·08	0·41	0·028	0·120	0·48	0·08	...	900–930
0·08	0·34	0·028	0·228	0·40	0·02	...	5070–5180
Steels made in Basic Bessemer Converter.							
0·13	1·25	0·172	0·076	0·04	0·02	3050	5605
0·03	0·46	0·046	0·270	0·03	0·01	5605	>7000
0·04	0·48	0·022	0·064	0·05	0·02	2300	4160

The authors had also established that sulphur was less active in accelerating the solution of mild steels than phosphorus, particularly when the copper content exceeded 0·05%. This content was usual to-day in steels made in the open-hearth furnace, when copper steels were being made which were returned in the form of scrap to the furnace. He had also observed that sulphur-bearing steels from the basic Bessemer converter dissolved more slowly than those carrying phosphorus (*see* Table A).

One fact was definitely established by the authors, namely, the relation between the contents of copper and of sulphur on the one hand and the rate of solution in acid on the other hand, which confirmed the researches of Hoar and Havenhand,[1] Bardenheuer and Thanheiser,[2] and others.

The authors had also succeeded in demonstrating the influence of cold-work, which was negligible in the case of an iron-phosphorus solution but sensible in the presence of insoluble impurities such as the sulphides of iron and of manganese, carbides of iron and alumina. It would seem that these facts should be explicable on the basis of electro-chemical theory. Finally, the authors had shown that the incubation period diminished rapidly when the temperature of the acid solutions was raised, a fact which he also had already had occasion to bring to light.[3]

[1] Hoar and Havenhand, *Journal of the Iron and Steel Institute*, 1936, No. I., p. 239P.

[2] Bardenheuer and Thanheiser, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1932, vol. 14, p. 1.

[3] Portevin and Herzog, Fourteenth Congress of Industrial Chemistry, 1934.

Professor Dr.-Ing. E. H. SCHULZ and Dr. F. EISENSTECKEN (Dortmund, Germany) wrote that the authors' observations on the attack by sulphuric acid on mild steels containing various amounts of sulphur, phosphorus and copper had been confirmed for hydrochloric acid by experiments carried out in the Research Institute of the Vereinigte Stahlwerke, A.-G., Dortmund, which would shortly be published elsewhere in detail. In these tests it was found that an increase in the sulphur content from 0·02 to 0·25% had no effect on the solubility in the acid, whilst raising the phosphorus content to 0·5% increased the attack considerably. Increasing copper contents from 0·3 to 0·62% reduced the acid solubility of the phosphorus-rich steels to the value for the low-phosphorus steel. In sulphur-containing steels also the addition of copper caused a diminution in the attack.

The greater rate of solution brought about by the presence of phosphorus in the metal became noticeable at a *p*H value less than 4, as was shown in 1% salt solutions acidified with hydrochloric acid. With smaller additions of hydrochloric acid and under conditions of atmospheric corrosion, however, sulphur and phosphorus had a quite different effect.

It seemed important to stress that the experiments carried out again clearly demonstrated that from acid-solubility values no conclusions could be drawn concerning the corrosion produced by water or by the atmosphere.

AUTHORS' REPLY.

Dr. EDWARDS and Mr. PHILLIPS replied that they would, first of all, like to say how pleased they were that Mr. Whiteley had so carefully studied the details of their work, and appreciated his kindly reference to its value. They were quite prepared to accept his remarks with regard to his detailed consideration of Tables I. and II., but they were not prepared to agree with his general conclusion. In this connection, all they wished to stress was that the differences to which Mr. Whiteley referred, during the early stages of acid attack, were so small as to be of so little significance that dogmatic conclusions could not be drawn from them. With relatively prolonged attack, there was no doubt that the authors' general conclusions were warranted.

Then, with regard to the criticism concerning the effects of cold-rolling, it was important to remember that the authors' conclusions, in this connection, were not based on Table II. They realised that the effect of cold-rolling some of the specimens which they had examined was relatively of no importance; indeed, in the case of the phosphorus series, all they had said was that there was a "tendency," indicating that cold-rolling increased the rate

of attack. The extent, however, was obviously very small for this series of specimens.

The position was, however, entirely different when considering specimens that contained appreciable quantities of undissolved impurities. Under these conditions, there was ample evidence in support of the view that cold-rolling did cause an increased rate of acid attack. Perhaps one of the most striking ways of emphasising this point was to examine the effects that were brought about by subsequently annealing, at progressively higher temperatures, specimens containing appreciable quantities, say, of sulphur, *see* Fig. 24.

The same was true when considering the question of alumina, or oxide of iron, &c.; whether Mr. Whiteley's criticism of the various references to the presence of alumina were valid or not they were not prepared to discuss at this stage. From Mr. Whiteley's own observation in this connection, it did not affect the main conclusions contained in the paper, and might well form the subject of a more detailed study, on some future occasion. They could not, however, help feeling some surprise to learn that Mr. Whiteley did not believe that alumina existed in Armco iron. In spite of the small points of criticism that Mr. Whiteley made in this, and other connections of a similar kind, he did not really appear to disagree with the idea that the presence of undissolved impurities gave rise to an increased rate of corrosion when the material had been heavily cold-rolled.

Turning now to Mr. Whiteley's remarks relating to the possible influence of arsenic, all they need say was that, in the phosphorus series, all specimens were made from the same batch of Armco iron, and, therefore, would have the same amount of arsenic in each case. They must, however, confess that they had not troubled to estimate the quantity of arsenic present, simply because the total amount of phosphorus and arsenic in the Armco iron used was well below 0·02%. The theory that Mr. Whiteley himself put forward to explain the influence of cold-rolling did not appear to the authors to be of much real significance—this, mainly because the cold-rolling effect of increasing quantities of phosphorus was almost negligible, as Mr. Whiteley himself had gone to so much trouble to prove. On the other hand, some theoretical consideration, similar to that put forward by the authors, was necessary to explain the indisputable fact that in all cases where non-dissolved impurities were present in appreciable quantities, cold-rolling increased the rate of acid attack, especially in the presence of sulphide of manganese, alumina, or oxide of iron.

Turning now to Dr. Hoar's remarks, the authors again wished to emphasise that there was ground for conflict between his and their views, particularly with regard to the fact that Dr. Hoar, in his work, completely neglected the influence of phosphorus, which had been proved to have a much greater effect than that of sulphur. Then, Dr. Hoar seemed to suggest that, in any work

of this kind, no attempt should be made to isolate a particular factor that it was desired to examine, or remove the effects of others. The authors still felt that, in all investigations of this kind, even when the ultimate object was for the results to be used for commercial purposes, it was necessary to carry out the work along scientific lines. Dr. Hoar almost suggested, though he could not really believe, that it was unnecessary to go to any trouble with regard to the selection of specimens which were to be examined for the study of a scientific problem. He, apparently, preferred to accumulate a large amount of unrelated data, and then to study them from a statistical point of view. For example, all the evidence proved that the influence of phosphorus was greater than that of any other element so far examined; and yet Dr. Hoar had some hesitation in accepting the facts contained in the present paper.

The authors were glad to note that Dr. Hoar said that the results obtained in the present paper were " of great fundamental interest." They were quite ready to leave it at that, for they realised that the " fundamental factors governing the relationships of composition and rate of acid attack upon steel " must be known before a complete appreciation of the commercial aspects of the problem could be understood.

Towards the end of Dr. Hoar's remarks, in expressing some appreciation of the value of the work, he said that " the authors had shown that the accelerating influence of phosphorus in nearly pure iron was greatly modified by the addition of carbon to the pure iron." The authors could not help feeling that this statement was rather misleading, for they believed they had most clearly shown that raising the phosphorus content in *steel* increased the rate of attack, and that the presence of increasing percentages of carbon in *steel* modified the effects of phosphorus. Having emphasised this point, they did not think it was necessary to deal with Dr. Hoar's observations regarding sulphur, &c.; they were quite prepared to let the experimental evidence that they had put forward in their paper speak for itself.

The authors were rather surprised to learn that Dr. Hoar had never noticed the " deposit " referred to in the paper, and which they mentioned as being due to a decomposition product of carbide of iron. They had taken the opportunity of discussing this question with other workers, who had all noticed it. In fact, it was one of the features which had been well known amongst students of steel metallurgy for a long time, and was frequently mentioned in the literature on the subject. Indications of its presence were to be seen whenever carbon steels were dissolved in very dilute mineral acids.

In answer to the point relating to the microstructures of the materials used, the authors wished to state that these were examined, but none of them were included in the paper, simply because they added so little to the study of the problem under consideration.

They could assure Dr. Hoar that the presence of massive cementite had not affected the results contained in their paper.

The authors were particularly pleased to have the suggestions made by Dr. Hoar concerning the desirability of making electrode-potential measurements of annealed and cold-rolled specimens, with a view to throwing more light upon the theoretical aspects of cold-rolling accelerating the rate of acid attack.

With regard to the final paragraph of Dr. Hoar's contribution, all that need be said, in answer, was that the authors' object had been to study the influence of varying quantities of different elements on the rate at which steel was attacked by acids. The information obtained was undoubtedly of direct application to the commercial production of tinplates and the uses to which the product was put. They readily agreed, however, that it was desirable, and indeed they hoped it would be found possible, to arrange to have normal-sized ingots made of widely varying chemical compositions, such as had been described in the present paper, from which tinplates could be produced, and the study of the behaviour of such materials, when used as food containers, examined. For this purpose, the authors considered it to be most desirable that experimental ingots of 10 cwt. or more should be made in an electric furnace. In this way much more reliable control could be obtained, and more systematic adjustment of the elements under consideration achieved.

The authors were particularly pleased to have Dr. Evans' interesting and extremely useful contribution to the discussion, and they valued his many helpful suggestions relating to future work. They recognised the point of criticism that he made concerning the possible disturbing effects that might arise as a result of bending the specimens. All they wished to say in this connection was that they believed that their method of bending to the same extent in all cases would reduce the error to a minimum and the effects would be practically the same in all cases.

The specimens were bent at right angles in the centre, round a radius of 3·5 mm. The details of the flask, &c., were as follows: The vessels used were wide-mouthed, flat-bottomed beaker flasks of 600 c.c. capacity, $2\frac{1}{2}$ in. wide at the mouth and $5\frac{3}{4}$ in. high. For each test, 250 c.c. of acid solution were used, which filled the flask to a depth of about 3·7 cm. The height of the liquid above the top edge of the steel was 1·7 cm. The flasks themselves were held by brass clips in a copper water-bath thermostatically controlled by a mercury bulb make-and-break, even circulation of the water being ensured by a large bladed propeller stirrer driven by a small motor. Temperature control was within 0·2° C.

They were in complete sympathy with Dr. Evans' observations to the effect that there was no known relationship between experiments carried out in a 6% solution of sulphuric acid and the attack by fruit juices in actual practice, and they were inclined to think

that much the same remarks could be made with regard to citric acid solutions. In the authors' work, sulphuric acid solutions were used because the results had a direct bearing upon the behaviour of steels during pickling, &c., and a 2% citric acid solution was selected because previous investigators considered that results obtained by this means might have some significance from the point of view of the canning industry. The authors agreed that more reliable data might be obtained by using various kinds of fruit juices, &c., and they proposed to turn their attention to this aspect of the problem in the near future. They were pleased to note the other points raised by Dr. Evans, but thought they did not call for answers.

In view of the contribution from Mr. Lewis, the remarks by Mr. Morris did not appear to need answering, other than to say that the authors believed there were so very many factors which had disturbing effects upon the rates of corrosion that they would hesitate to accept specimens for work of this kind unless they knew the details of their history.

They were very pleased to have Dr. Hudson's contribution to the discussion, which they regarded as a useful supplement to their work. There was only one point which needed to be dealt with, and that was to say that the sulphuric acid used in the authors' experiments was the best chemically pure for analytical purposes.

It was a source of considerable gratification to the authors to have the appreciative observations made by Mr. Lewis; they felt that these represented the feelings of others engaged in the manufacture of tinplates, and, for that reason alone, they were glad to have a record of Mr. Lewis's views.

Whilst thanking Mr. Rhodes for his written contribution, the answers already given to others made the authors think that it was only necessary to reply to his last paragraph. In that connection, they would like to say that they also felt that their work had now reached a stage at which there was an excellent opportunity for co-operation with can-makers and food-canners. With this in view, they hoped it would be possible to make ingots of special composition, similar in many respects to those referred to in the present paper, and from these to have tinplates for food-containers made, and, later, examined with the object of studying their behaviour under carefully controlled conditions.

It was especially pleasing to the authors to note the remarkable agreement which existed between Professor Portevin's work and conclusions and their own. They were particularly interested in his reference to the figures he gave for Bessemer steel. It was also most encouraging to find that he accepted their evidence and conclusions concerning the influence of insoluble impurities and heavy cold-rolling, which they considered to be of much theoretical significance.

The authors were delighted to have the contribution by Pro-

fessor Schulz and Dr. Eisenstecken, and would like to say how much they looked forward to the publication of the results to which they referred. They (the authors) readily agreed with Professor Schulz and Dr. Eisenstecken that acid solubility tests had not necessarily any relation with those of water or atmospheric corrosion; no doubt, the main reason for this was that there was no real comparison between the rates at which the products of corrosion were removed from the surfaces of the specimens when examined under these widely differing conditions.

THE EFFECT OF COPPER ON SOME ALLOY STEELS.*

By R. HARRISON, B.Sc. (Woolwich).

Synopsis.

The mechanical properties of a number of alloy steels containing from 1 to 6% of copper in the oil-hardened and tempered and in the temper-hardened conditions, have been examined. The maximum increase in hardness due to temper-hardening was obtained in a low-carbon steel containing 0·5% of chromium and 1·6% of copper. Increasing the alloy content in order to obtain a higher final hardness introduced a tendency to air-hardening, and the temper-hardening effect was gradually masked by the softening due to normal tempering. The highest tensile strength obtained by temper-hardening alone—that is, in the absence of any air-hardening during normalising—was just over 50 tons per sq. in. The low Izod impact figures usually associated with the temper-hardening process were considerably improved by increasing the reheating time or temperature.

Although temper-hardening may provide material of good properties when the composition and treatment are carefully chosen and may prove useful in particular cases, it is not likely to displace the usual method of oil-hardening and tempering for ordinary materials of construction.

Copper may, however, prove to be a useful alloy element in steels to be used in the hardened and tempered condition. Considerably higher tensile properties were obtained in a medium-carbon steel containing 1·0% of copper than in a similar steel containing 1·4% of nickel, and the properties of a 3·4% copper, 0·9% chromium steel were slightly better than those of a 3·5% nickel, 0·9% chromium steel.

If difficulties in mechanical treatment result from the limitation of the forging temperature necessitated by high copper contents, a steel containing nickel and copper, free from these limitations, may be employed without detriment to the mechanical properties.

Copper is now commonly added to structural steels in small amounts, 0·2–0·5%, to increase their resistance to atmospheric corrosion, but in spite of the existence of a comprehensive survey by Gregg and Daniloff,[1] little information is available on the effects of larger amounts of copper on the mechanical properties.

Previous Work.

Kinnear [2] appears to have made the earliest observation that steels containing copper undergo an increase in tensile strength on

* Communication from the Research Department, Woolwich, received February 2, 1938.

tempering at 500° C., but the effect was first examined in detail by Nehl [3] and by Buchholtz and Köster,[7] who recognised the change as being due to a precipitation phenomenon. These workers defined the heat treatment necessary to bring about the maximum effects and showed that a comparatively slow rate of cooling (6 hr. to cool from 950° to 15° C.) was sufficiently rapid to retain the supersaturated solid solution. This has an important practical consequence in that large and complicated forgings or castings may be hardened without introducing the danger of warping or cracking by quenching. There is a further advantage in the process in that on reheating at 500° C. hardening takes place uniformly throughout the section.

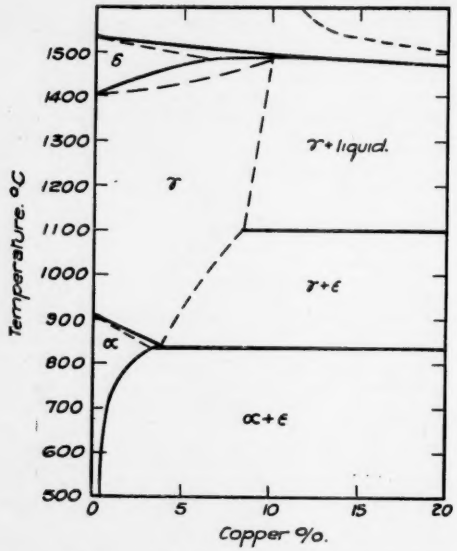

FIG. 1.—Iron-Rich Portion of Iron-Copper Equilibrium Diagram (Hansen [11]). The limit of the α solid solution, according to Norton, is 1·4% of copper at 850° C.

An examination of a wide range of alloy steels carried out by Smith and Palmer [4] showed that the presence of the usual alloy elements did not appreciably influence the response of the steels to hardening by copper precipitation. Jones [5] examined the effect of copper up to 1·2% on the mechanical properties of normalised 1·0% chromium steels, and found this addition beneficial in the normalised condition. Williams and Lorig,[6] in an investigation of the

effect of copper on carbon steel and on 1·0% chromium steels in the annealed, normalised, and temper-hardened conditions, showed that the tensile strength was increased by additions of up to about 3·0% of copper.

An approximate determination of the limits of solid solubility of copper in iron was made by Buchholtz and Köster,[7] who gave the solubility as 3·4% at the eutectoid temperature of 810° C., falling to 0·2% at atmospheric temperature. A later determination by Norton [8] placed the solubility at 1·4% at the eutectoid temperature, which he tentatively set at 850° C., falling to 0·35% at 650° C., below which it remains constant.

The eutectoid composition and temperature were placed by Ruer and Goerens [9] at 2·3% of copper and 833° C., but by Buchholtz and Köster [7] at 5·5% of copper and 810° C. The eutectoid composition was not determined by Norton. The solubility of copper in the γ solid solution was found by Vogel and Dannöhl [10] to be 8·5% at 1094° C. The iron-rich end of the equilibrium diagram for iron-copper alloys as given by Hansen [11] is shown in Fig. 1.

Present Investigation.

The present investigation was undertaken for the Metallurgy Board of the Department of Scientific and Industrial Research, to whom the author is indebted for permission to publish this paper, and was intended to form a preliminary survey of the possibility of utilising the temper-hardening effect of copper, in steels containing other alloy elements, to develop a structural steel of high yield strength. It was found, however, that copper might prove to be a useful alloy element in steels used in the oil-quenched and tempered condition, and the mechanical properties after these treatments were also examined.

Materials Used.

The compositions of the steels used are given in Table I. and details of manufacture and forging in Table II. The maximum temperature of reheating for rolling or forging was limited to 1050° C. to avoid melting any metallic copper formed in the scale and the consequent possibility of intercrystalline penetration. No difficulty was experienced in working the steels listed in Table I., but an attempt to roll 0·5% chromium steels containing more than 5·0% of copper with low carbon or more than 4·0% of copper with medium carbon contents, resulted in the ingots bursting at the first pass.

Thermal Critical Ranges.

The critical ranges of steels 1–9 and 22–33 were determined by means of a platinum/platinum-rhodium thermocouple and a Carpenter-Stansfield potentiometer used in conjunction with a

TABLE I.—*Chemical Analyses of Steels Used.*

Steel No.	Mark.	Carbon. %.	Silicon. %.	Manganese. %.	Sulphur. %.	Phosphorus. %.	Nickel. %.	Chromium. %.	Copper. %.
1	*MJD*	0·048	0·21	0·28	<0·005	0·021	...	0·50	1·62
2	*MJE*	0·040	0·24	0·28	0·021	0·027	...	0·51	2·13
3	*MJF*	0·054	0·24	0·39	0·021	0·021	...	0·52	3·14
4	*MJG*	0·040	0·19	0·40	<0·005	0·022	...	0·51	4·02
5	*NEC*	0·040	0·15	0·28	0·011	0·020	...	0·49	5·20
6	*MJH*	0·29	0·26	0·40	0·009	0·026	...	0·51	1·54
7	*MJJ*	0·28	0·35	0·47	0·009	0·020	...	0·48	2·06
8	*MJK*	0·23	0·25	0·32	0·039	0·027	...	0·53	3·15
9	*MJL*	0·20	0·19	0·43	0·021	0·018	...	0·49	4·15
10	*NEB*	0·24	0·20	0·31	0·006	0·020	...	0·47	4·05
11	*NED*	0·24	0·19	0·36	0·008	0·022	...	0·88	4·00
12	*NYX*	0·25	0·18	0·24	0·008	0·023	...	1·47	2·14
13	*NYX*	0·32	0·18	0·23	0·009	0·023	...	1·42	2·12
14	*OGM*	0·32	0·17	0·55	0·015	0·028	2·24	...	1·19
15	*OGH*	0·35	0·17	0·46	0·016	0·025	2·17	...	2·10
16	*OGJ*	0·29	0·15	0·51	0·015	0·025	2·25	...	4·23
17	*OGN*	0·30	0·18	0·55	0·020	0·026	2·05	0·63	1·19
18	*OGK*	0·31	0·17	0·52	0·020	0·024	2·07	0·61	2·20
19	*OGO*	0·33	0·16	0·62	0·016	0·025	2·08	1·15	1·18
20	*OGL*	0·34	0·20	0·60	0·022	0·024	2·15	1·18	2·33
21	*NYZ*	0·28	0·13	0·18	<0·005	0·019	2·15	1·41	1·98
22	*QZN*	0·30	0·28	0·44	<0·005	0·025	3·50	0·90	...
23	*QZO*	0·27	0·21	0·38	<0·005	0·025	2·55	0·80	1·00
24	*QZP*	0·26	0·25	0·44	<0·005	0·025	1·55	0·85	2·03
25	*QZQ*	0·27	0·26	0·43	<0·005	0·030	...	0·85	3·40
26	*OUO*	0·30	0·24	0·45	0·037	0·037	...	...	...
27	*OVK*	0·27	0·24	0·60	0·035	0·040	...	...	1·06
28	*OXP*	0·26	0·23	0·62	0·034	0·039	1·40	...	...
29	*OXW*	0·26	0·22	0·72	0·036	0·040	1·49	...	1·00
30	*PAB*	0·27	0·23	0·66	0·036	0·039	1·54	0·61	...
31	*OZU*	0·31	0·22	0·70	0·037	0·038	1·36	0·48	1·02
32	*OUV*	0·30	0·24	1·21	0·034	0·043	...	...	...
33	*PJW*	0·27	0·21	1·48	0·037	0·040	...	...	1·05
34	*OXH*	0·29	0·21	1·90	0·036	0·041	...	...	1·00
*A**	...	0·31	...	0·46	...	...	...	0·66	...
*B**	...	0·29	...	0·46	...	...	...	0·67	0·50
*C**	...	0·27	...	0·52	...	...	...	0·62	1·06

* *Journal of the Iron and Steel Institute*, 1930, No. I., p. 209.

Rosenhain plotting chronograph. The results obtained are given in Table III.

Copper has a much smaller influence than nickel in depressing the critical points, and the substitution of copper for the nickel in the nickel-chromium-copper steels Nos. 22–25 therefore resulted in a marked rise in all points with the exception of an initial fall in Ac_1 at 1% copper.

TABLE II.—*Sizes of Ingots and Forged Bars.*

Steels Nos.	Type of Furnace.	Ingot.		Forging.
		Weight. Lb.	Section.	
1–11	High-frequency	30	3 in. × 3 in.	1¾ in. × ½ in.*
12, 13, 21	High-frequency	60	4½ in. × 4½ in.	3½ in. in dia.
14–20	High-frequency	12	2 in. × 2 in.	1½ in. × ½ in.
22–25	High-frequency	40	3½ in. × 3½ in.	1½ in. × ¾ in.
26–34	Tropenas converter	100	4½ in. × 4½ in.	3½ in. in dia.

* Rolled.

TABLE III.—*Critical Ranges. Effect of Copper.*

Steel No.	Composition. %.					Heating.			Cooling.	
	Carbon.	Manganese.	Nickel.	Chromium.	Copper.	Ac_2. ° C.		Ac_3 End. ° C.	Ar_3 Max. ° C.	Ar_2. ° C.
1	0·048	0·28	...	0·50	1·62	752		880	819 / 812	746
2	0·040	0·28	...	0·51	2·13	754		876	815 / 810	748
3	0·054	0·39	...	0·52	3·14	758		876	807	748
4	0·040	0·40	...	0·51	4·02	757		867	799	750
						Ac_1. ° C.		Ac_3 End. ° C.	Ar_3 Max. ° C.	Ar_1 Max. ° C.
						Beginning.	Max.			
6	0·29	0·40	...	0·51	1·54	734	744	832	732	679
7	0·28	0·47	...	0·48	2·06	737	746	...	734	684
8	0·23	0·32	...	0·53	3·15	736	748	837	741	679
9	0·20	0·43	...	0·49	4·15	733	744	819	728	666
22	0·30	0·44	3·50	0·90	...	710	722	765	612	...
23	0·27	0·38	2·55	0·80	1·00	704	719	786	638	601
24	0·26	0·44	1·55	0·85	2·03	718	731	788	658	635
25	0·27	0·43	...	0·85	3·40	738	746	813	715	676
26	0·30	0·45	...	...	...	733	739	828	777	686
27	0·27	0·60	...	...	1·06	732	736	832	750	662
28	0·26	0·62	1·40	...	...	719	723	815	721	648
29	0·26	0·72	1·49	...	1·00	705	713	804	683	615
30	0·27	0·66	1·54	0·61	...	722	731	792	683	651
31	0·31	0·70	1·36	0·48	1·02	717	724	792	671	640
32	0·30	1·21	...	...	...	721	728	820	723	651
33	0·27	1·48	...	...	1·05	716	721	812	689	623

1–9	Heating rate at Ac_1, 6–7° C. per min. Cooling rate at Ar_3, 5½–4° C. per min. Maximum temperature, 950° C.
22–33	Heating rate at Ac_1, 7½–9½° C. per min. Cooling rate at Ar_3, 8¼–6½° C. per min. Maximum temperature, 925° C.

In the 0·5% chromium steels Nos. 1–9, increasing copper content had no effect until this reached 4%, when there was a fall in the A_3 points.

The addition of 1% of copper lowered the Ac_3 points of the nickel steel No. 28 and the manganese steel No. 32 by 11° and 8° C., respectively, but had no effect on this point in the carbon steel No. 26 or the nickel-chromium steel No. 30. In each of these steels the Ar points were appreciably lowered by the copper addition.

Temper-Hardening.

Treatment of Small Pieces.

The response of the steels to the temper-hardening treatment was followed by investigating the change of hardness undergone by specimens air-cooled from temperatures ranging from 700° to 950° C. and subsequently reheated at temperatures between 400° and 700° C. for various times. Representative curves of the results are given in Figs. 2 to 9.

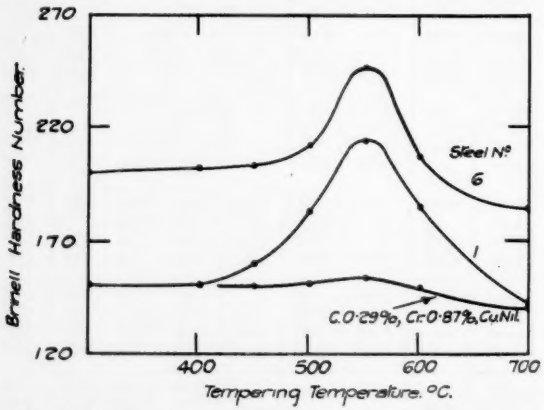

Fig. 2.—Effect of Tempering for ½ Hr. after Normalising at 800° C. on the Brinell Hardness Number.

Among the 0·5% chromium steels, after normalising from 800° C. the maximum increase in hardness occurred in the low-carbon series, and the maximum hardness attained in any of the steels examined was not affected to an important extent by a variation in the tempering temperature between 450° and 550°, though the time of heating necessary to give the maximum hardness was shorter with the higher tempering temperature. An increase in the copper

content from 1·6 to 4·0% made no difference to the extent of the temper-hardening as measured by the increase in hardness on tempering. No corresponding change in hardness occurred in a similar chromium steel free from copper (Figs. 2 and 3).

An increase in the normalising temperature above 800° C. led to partial air-hardening of the chromium-copper steels containing over 3% of copper (Fig. 4), but the effect was less pronounced than in the more strongly air-hardening nickel-chromium steels with 1–2% of copper. As the normalising temperature was increased the temper-hardening effect was gradually masked by the softening due to tempering which succeeded air-hardening (Fig. 5). The air-hardening effect in the nickel-copper steels was somewhat similar

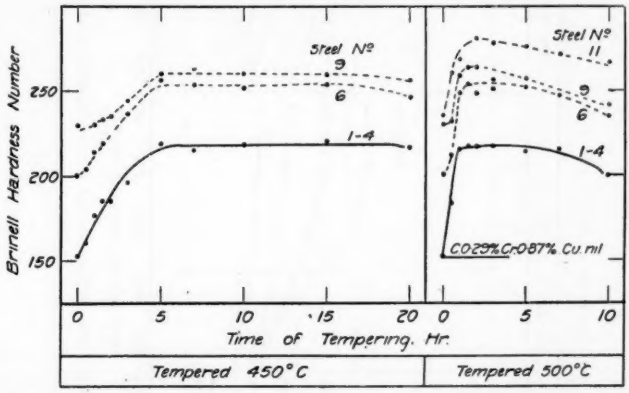

FIG. 3.—Effect of Temperature and Time of Tempering on the Brinell Hardness Number after Normalising at 800° C.

to that in the chromium-copper steels, but the maximum temper-hardening in the nickel-copper steels (Fig. 6) was considerably less than in the chromium-copper or nickel-chromium-copper steels. In these, as in other instances, the temper-hardening effect reached its maximum before the copper content exceeded 2%.

The steels thus fell into two groups, according to whether the effect of temper-hardening or of air-hardening predominated under the conditions of treatment, including the size of specimen treated. When pronounced air-hardening had occurred, however, as in the nickel-chromium-copper steels, the fall of hardness on tempering was checked, and the hardness remained constant or rose slightly on continued tempering (Fig. 7).

The behaviour of low-carbon copper-chromium steels containing 1·6% of copper was similar after oil-hardening from 950° C. to that after air-cooling from 950° C. With 4% of copper, however, the

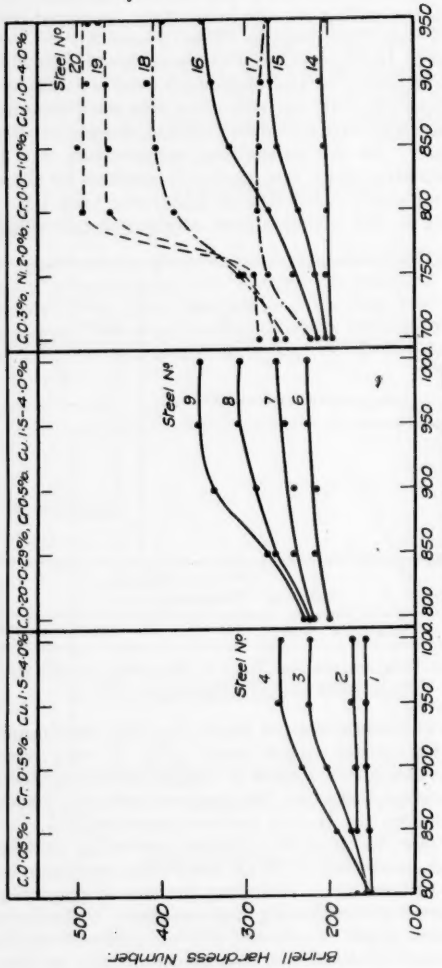

FIG. 4.—Effect of Normalising Temperature on the Brinell Hardness of Pieces $1\frac{1}{2} \times \frac{1}{2} \times \frac{1}{2}$ in.

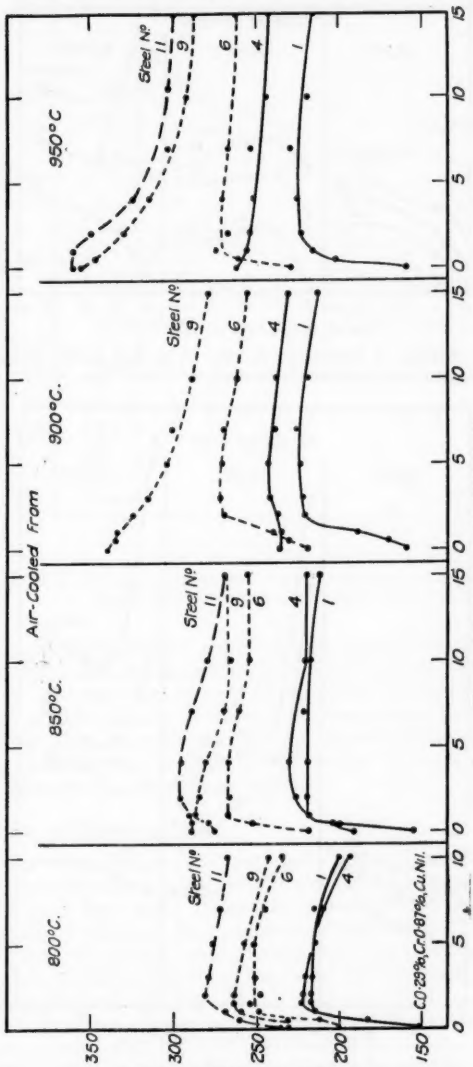

FIG. 5.—Effect of Time of Reheating at 500° C. and of Initial Normalising Temperature on the Brinell Hardness of Steels Nos. 1–11.

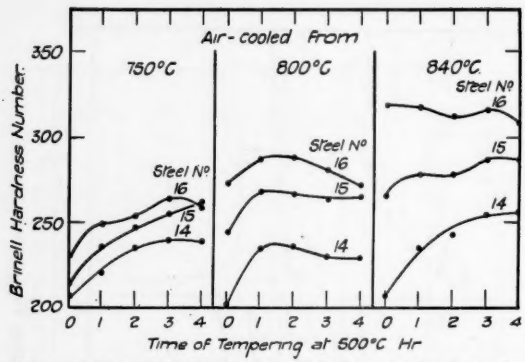

FIG. 6.—Effect of Time of Reheating at 500° C. and of Initial Normalising Temperature on the Brinell Hardness of Steels Nos. 14–16.

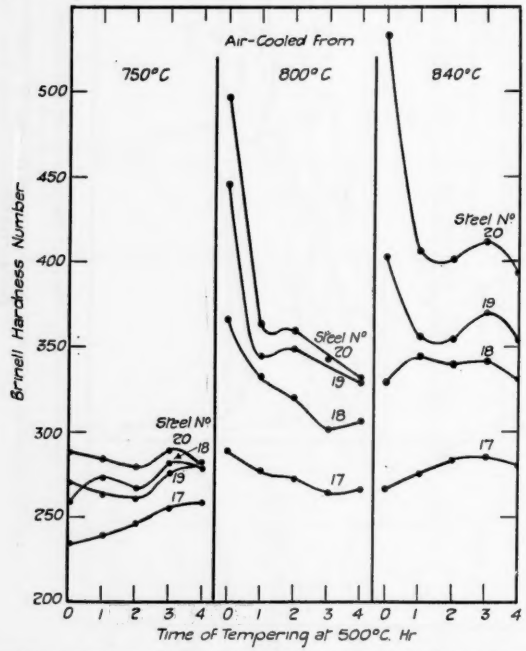

FIG. 7.—Effect of Time of Reheating at 500° C. and of Initial Normalising Temperature on the Brinell Hardness of Steels Nos. 17–20.

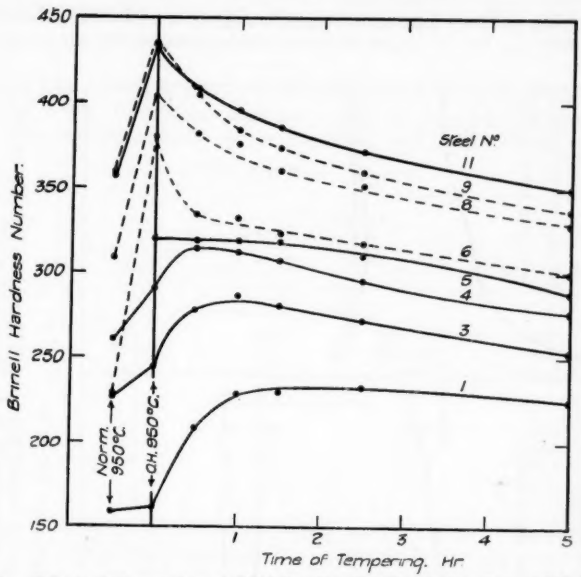

FIG. 8.—Effect of Tempering at 500° C. after Oil-Hardening from 950° C. on the Brinell Hardness of Steels Nos. 1–11.

steel was slightly harder after oil-quenching (280) than after air-cooling (260), and, moreover, hardened further to 320 after tempering (Fig. 8), whereas the air-cooled specimen softened continuously (Fig. 5). This greater tendency to temper-hardening after oil-quenching may possibly be due to the retention of rather more copper in solid solution when the cooling through the eutectoid transformation has been more rapid.

Specimens of Larger Section.

It was clear that in the treatment of small pieces the temper-hardening effect was not likely to give as hard a product as one which had received the usual treatment of quenching and tempering. The behaviour of 3¼-in. dia. specimens of selected steels was therefore investigated, the initial cooling being done on specimens 6 in. long, smaller pieces being cut from the mass for tempering. The steels used were Nos. 12, 13 and 21.

The chromium-copper steels showed temper-hardening after air-cooling from 800° C., but the effect was masked by some air-hardening when the normalising temperature was 950° C. In small sections the nickel-chromium-copper steel was sufficiently air-

hardening to show a progressive softening after an initial air-cooling from 800° C., but in larger sections the temper-hardening tendency

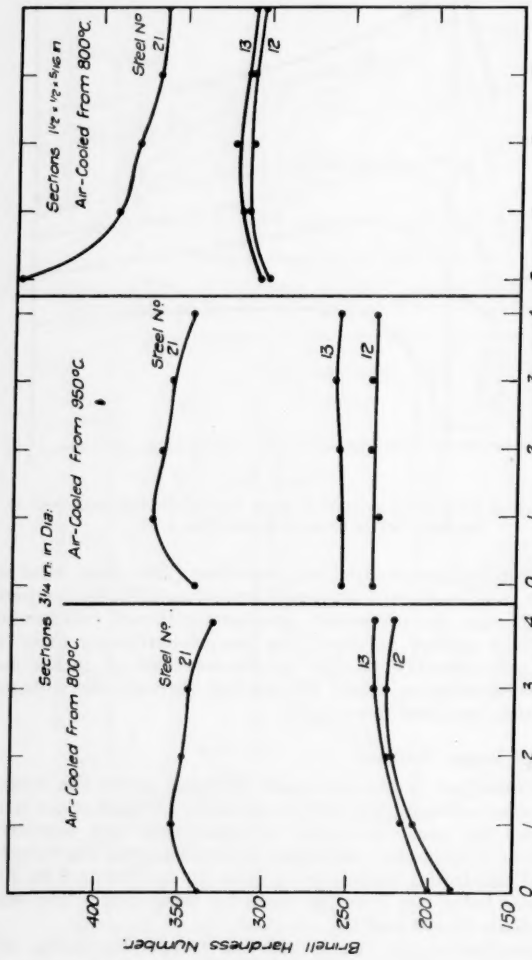

FIG. 9.—Effect of Time of Reheating at 500° C. on the Brinell Hardness of Steels Nos. 12, 13 and 21. Initially air-cooled from 800° C. and 950° C. in sections 3¼ in. in dia. and 1½ × ½ × 5/16 in.

showed itself in maintaining the hardness at an almost constant value on tempering at 500° C. These results are shown in Fig. 9.

The hardness values of these steels after various rates of cooling are given in Tables IV. to VI.

TABLE IV.—*Effect of Size of Section Treated on the Brinell Hardness of 1·4% Chromium and on 2·0% Nickel, 1·4% Chromium Copper Steels Cooled in Air from 800° and from 950° C.*

Brinell Hardness Numbers.

Steel No.	Size of Section.			
	6 × 3½ in. in dia. at Centre.	6 × ¾ × ¾ in.	6 × ½ × ½ in.	1½ × ½ × $\frac{1}{16}$ in.
	Normalised at 800° C.			
12	178	204	209–308	300
13	190	229	293–321	304
21	342	363	412–451	446
	Normalised at 950° C.			
12	216	300	304	314
13	233	312	328	329
21	343	394	430	449

TABLE V.—*Effect of Rate of Cooling on the Brinell Hardness of Sections ½ in. Square. Cooled from 950° C.*

Brinell Hardness Numbers.

Steel No.	Average Cooling Rate.			
	Oil. 16° C. per sec.	Air. 4° C. per sec.	Furnace.	
			⅛° C. per sec.	$\frac{1}{250}$° C. per sec.
12	414	304	233	148
13	464	328	260	162
21	444	430	344	232

TABLE VI.—*Brinell Hardness Tests across the Middle of a Central Slice cut from Sections 6 in. long × 3½ in. in dia. after Cooling in Air from 950° C.*

Brinell Hardness Numbers.

Steel No.	Position of Test.				
	Outside.	Centre.			Outside.
12	228	219	216	219	224
13	248	243	233	246	249
21	339	344	343	344	347

Mechanical Properties.

The tensile properties were determined on test-pieces 0·357 in. in dia. with a parallel portion $2\frac{1}{4}$ in. long, except in the case of steels Nos. 12, 13 and 21–25, for which a test-piece 0·564 in. in dia. with a gauge length of 2 in. was used. Limits of proportionality and yield points were determined by means of a Ewing extensometer, the yield point being taken as the load giving a permanent extension of 0·2% (0·004 in. on 2 in.). The elongation was measured on a gauge length of 1·26 in. ($L = 4\sqrt{a}$). The notched-bar impact tests were carried out in a 120-ft.lb. Izod machine on 3-notch test-pieces of the B.S.I. standard form (45° V notch with a root radius of 0·25 mm. and 2 mm. deep). All tests were taken in the longitudinal direction.

Chromium-Copper Steels.

Carbon 0·05 *and* 0·20–0·29%, *Chromium* 0·5%, *Copper* 1·5–5·0% (*Steels* 1–11).

As-Rolled (*Table VII.*).—In the low-carbon series, the properties in the as-rolled condition were remarkably good, a yield point of 32 tons per sq. in., with an Izod impact figure of 95 ft.lb. and good ductility, being obtained for the 1·5% copper steel. Increasing the copper content produced a small and irregular increase in the maximum load. In the medium-carbon series there was a marked increase in the tensile strength with increasing copper content, but the Izod figure fell from a maximum value of 29 ft.lb. to 3 ft.lb. at 4% of copper.

Normalised at 950° *C.* (*Table VII., Fig.* 10).—The occurrence of air-hardening was shown in the results of tensile tests made on specimens which had been normalised by heating for ½ hr. at 950° C. followed by cooling in air. These results are given in Fig. 10. In both series the interval between the limit of proportionality and the yield point increased progressively with an increase in copper content above 2·0%. Very good Izod impact figures were obtained in the low-carbon steels containing up to 3·0% of copper, but with higher copper contents considerable scatter appeared. In the medium-carbon series the impact figure fell progressively from 35 ft.lb. to 5 ft.lb. at 4·0% of copper.

Normalised at 950° *C. and Reheated for* 2 *Hr. at* 500° *C.* (*Table VII., Fig.* 10).—The low-copper steels, in which little or no air-hardening had occurred, were temper-hardened, an increase in the limit of proportionality, yield point and maximum load being accompanied by a fall in the elongation. Those steels which had been air-hardened by the normalising treatment softened on reheating but the tempering effect did not appear to be complete in the medium-carbon series. The Izod impact figure was adversely affected by the reheating treatment; erratic results were obtained

TABLE VII.—*Mechanical Properties of the Chromium-Copper Steels, Normalised and Reheated.*

Treated in Sections $1\frac{3}{4} \times \frac{1}{2}$ in. and 5 in. long.

Steel No.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
			As-Rolled.					
1	30	32·0	35·0	0·91	34	70	95	174
2	28	29·0	31·6	0·91	37	71	96	156
3	29	32·0	35·5	0·90	35	77	110	175
4	30	35·5	39·0	0·91	29	70	85	195
5	34	37·5	38·2	0·98	32	75	95	185
6	27	31·0	44·2	0·70	29	56	29	205
7	29	37·0	51·1	0·72	24	54	20	243
8	38	42·0	54·2	0·77	22	47	9	265
9	41	51·5	65·0	0·79	19	44	3	307
10	45	50·0	59·6	0·84	22	50	16	277
11	37	51·5	64·1	0·80	21	51	15	298
			Normalised at 950° C.					
1	23	26·0	33·9	0·76	37	72	107	155
2	27	31·0	34·2	0·90	35	70	96	166
3	30	35·5	39·4	0·90	30	72	111	197
4	31	39·0	46·0	0·85	27	67	22–67	228
5	32	41·5	44·3	0·93	27	70	12–83	219
6	23	31·0	47·6	0·65	27	58	35	217
7	37	40·0	52·0	0·77	27	53	27	237
8	40	47·5	60·2	0·78	21	47	10	283
9	40	55·0	69·3	0·79	21	41	5	324
10	39	55·5	70·3	0·79	17	38	4	329
11	28	52·0	70·0	0·74	21	41	11	...
			Normalised at 950° C., Tempered 2 Hr. at 500° C.					
1	36	37·5	43·9	0·85	29	64	9–38	221
2	37	39·0	43·9	0·89	30	65	27–39	222
3	34	37·7	41·7	0·90	32	73	105	208
4	34	39·0	43·9	0·89	27	70	46–87	225
5	39	43·0	44·9	0·95	27	67	69	224
6	33	41·0	56·0	0·73	23	51	4	265
7	41	44·0	55·1	0·80	25	55	17	263
8	40	45·5	56·3	0·80	22	49	12	276
9	41	50·0	61·8	0·81	22	49	14	302
10	43	53·0	66·8	0·79	21	45	6	317
11	42	61·0	72·0	0·84	19	40	12	341
			Normalised at 800° C.					
1	16	21·5	28·8	0·74	44	75	101	136
2	19	24·0	29·5	0·81	44	75	99	141
3	21	26·0	29·8	0·87	44	80	112	145
4	20	25·0	30·2	0·82	41	79	115	148
5	27	30·5	33·3	0·91	38	77	103	158
A	13	20·0	33·9	0·59	36	66	67	151
B	15	21·0	34·9	0·60	34	63	67	151
C	21	24·8	37·8	0·66	33	62	59	170
6	24	29·0	42·3	0·68	32	59	45	196
7	33	35·5	45·0	0·78	30	60	45	213
8	30	34·0	42·6	0·80	29	59	39	204
9	30	36·0	45·2	0·79	26	57	54	216
10	38	42·0	48·6	0·86	25	57	55	227

TABLE VII. (*continued*).

Steel No.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
			Normalised at 800° *C., Tempered* 2 *Hr. at* 500° *C.*					
1	34	36·0	42·0	0·85	30	65	16–32	210
2	35	37·5	41·3	0·90	32	65	47	207
3	35	38·0	41·0	0·92	32	72	79–108	207
4	32	36·0	40·1	0·90	30	72	15–42	205
5	40	42·0	43·2	0·97	35	70	101	208
6	37	40·5	52·5	0·77	26	54	18	250
7	40	44·5	53·8	0·82	26	55	22	252
8	39	42·5	51·0	0·83	25	55	19	249
9	41	45·0	52·7	0·85	27	57	22	254
10	46	49·0	54·1	0·90	24	55	18	255
			Normalised at 800° *C., Tempered* 15 *Hr. at* 500° *C.*					
1	30	33·0	39·6	0·83	29	69	99	199
2	31	34·0	39·8	0·85	30	69	93	200
3	33	35·5	39·5	0·90	30	73	105	197
4	31	34·0	38·8	0·87	32	73	115	196
5	40	42·0	43·3	0·97	32	72	105	210
6	32	37·0	49·6	0·74	25	57	23	236
7	37	39·5	50·0	0·79	25	58	32	239
8	35	40·5	49·3	0·82	25	57	20	238
9	35	39·0	50·0	0·78	27	58	28	241
10	39	43·0	50·8	0·84	24	50	31	240
			Normalised at 800° *C., Tempered* 2 *Hr. at* 550° *C.*					
1	32	34·0	40·7	0·83	29	65	29	203
2	33	36·0	41·1	0·87	30	66	91	205
3	34	36·0	39·7	0·91	33	73	117	196
4	31	34·0	39·4	0·86	32	69	91	196
5	37	39·5	42·4	0·93	29	60	92	207
6	34	38·0	50·9	0·74	25	55	20	242
7	39	42·0	51·6	0·81	27	58	27	249
8	40	42·0	50·5	0·83	27	55	20	244
9	40	43·5	51·7	0·84	25	55	29	251
10	43	45·0	50·8	0·88	25	56	28	240
			Normalised at 800° *C., Tempered* 2 *Hr. at* 600° *C.*					
1	26	28·5	33·6	0·84	32	73	45–90	162
2	28	29·5	34·6	0·85	32	72	96	166
3	29	30·0	33·8	0·88	36	77	115	163
4	30	32·0	34·6	0·92	35	77	96	165
5	32	34·0	35·5	0·95	36	77	101	174
6	30	32·0	44·0	0·72	29	60	40	200
7	33	36·0	45·4	0·79	29	62	53	205
8	34	37·0	44·7	0·82	29	62	53	209
9	36	38·5	45·4	0·84	29	62	52	213
10	34	38·0	44·9	0·84	30	63	63	207

in the low-carbon series and the maximum value in the medium-carbon series was only 17 ft.lb.

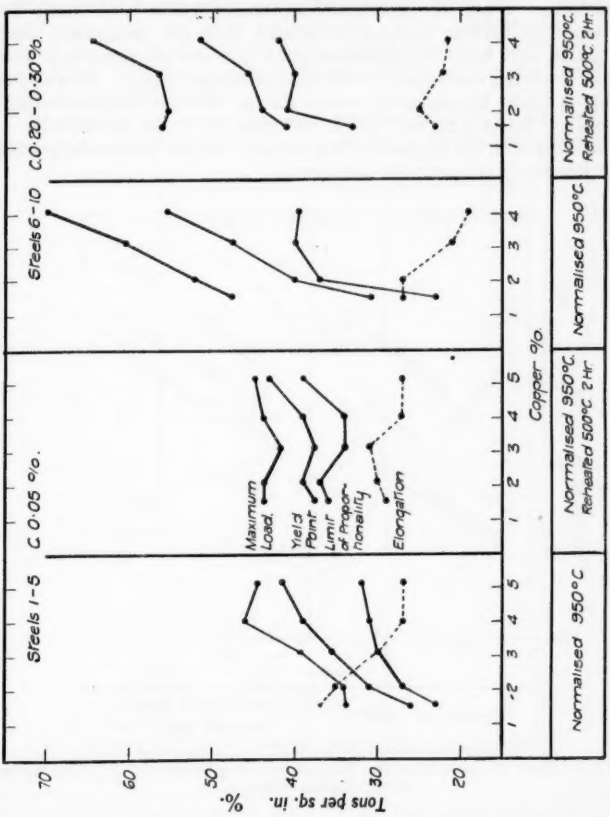

FIG. 10.—Mechanical Properties of Steels Nos. 1–10. Normalised at 950° C. and normalised and reheated at 500° C.

Normalised at 800° *C.* (*Table VII., Figs.* 11 *and* 12).—The influence of copper on the mechanical properties of the medium-carbon series, after normalising at 800° C., was masked by the considerable range in the carbon content, which varied from 0·20 to 0·29%. The effect of the carbon content, up to 0·24%, on the properties of a steel containing 0·5% of chromium and 4·0% of copper is shown in Fig. 11. The maximum load, yield point, and limit of proportionality were each increased by approximately 18 tons per sq. in. by an increase in the carbon content from 0·04 to 0·24%. In Fig. 12, therefore, the curves showing the effect of copper have been interrupted between 2% and 3% of copper to separate the steels containing 0·27–0·31% of carbon from those containing

0·23–0·24%. When the necessary adjustment has been made for the change in carbon content, it is seen that the maximum load, yield point, and limit of proportionality increase progressively with increasing copper content up to the maximum of 4·0%. It was not possible to make the same allowance for the effect of carbon content on the Izod impact figure, which fell from 67 ft.lb. to 45 ft.lb. at 2·0% of copper in the higher-carbon group. There was no indication of any tendency towards air-hardening.

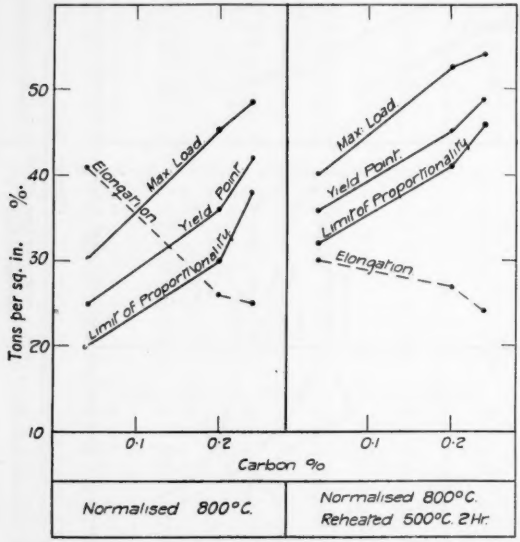

Fig. 11.—Effect of Carbon on the Mechanical Properties of 0·5% Chromium, 4·0% Copper Steels.

The properties of the steels containing 0·05% of carbon are shown in the first panel of Fig. 13. Increasing the copper content raised the yield point and limit of proportionality and, to a lesser extent, the maximum load, but the effect of a variation in copper content was much smaller than in the medium-carbon steels. The resistance to notched-bar impact was high—over 99 ft.lb.—in all the low-carbon steels.

Normalised at 800° *C. and Reheated at* 500–600° *C.* (*Table VII., Fig.* 13).—The maximum increase in tensile properties was obtained by tempering for 2 hr. at 500° C. in both the low- and the medium-carbon series; in the 1·5% copper steels, the limits of proportionality were increased by 18·0 and 13·0 tons per sq. in., the yield points by

14·5 and 11·5 tons per sq. in., and the maximum loads by 13·2 and 10·2 tons per sq. in., respectively. The notched-bar impact values, however, were poor; considerable scatter occurred in the low-carbon series, and the maximum value in the medium-carbon series was only 22 ft.lb.

Increasing the tempering temperature to 550° C. or the time of tempering at 500° C. to 15 hr. produced a marked improvement in

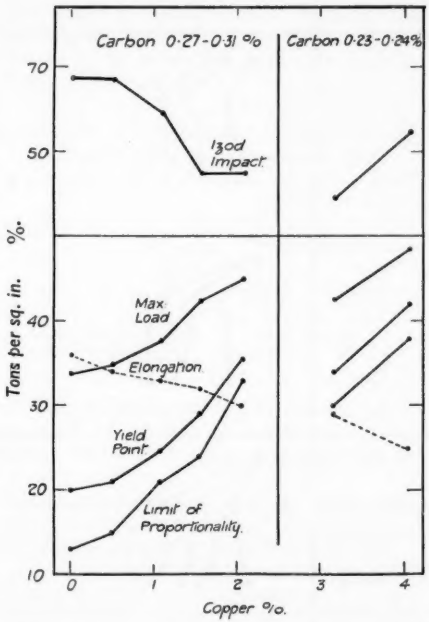

FIG. 12.—Effect of Copper on the Mechanical Properties of Steels containing 0·2–0·3% of Carbon and 0·5% of chromium. Normalised at 800° C.

the Izod impact values of the low-carbon series without materially affecting the tensile properties. In the medium-carbon series, however, high impact values were not obtained until the tempering temperature was raised to 600° C., when the tensile properties were not appreciably different from those obtained by normalising alone.

The best combination of properties was obtained in steel No. 7, containing 2·0% of copper, after normalising at 800° C. and tempering for 2 hr. at 550° C., *viz.*, maximum load of 51·6 tons per sq. in., yield point of 42·0 tons per sq. in., limit of proportionality of 39·0

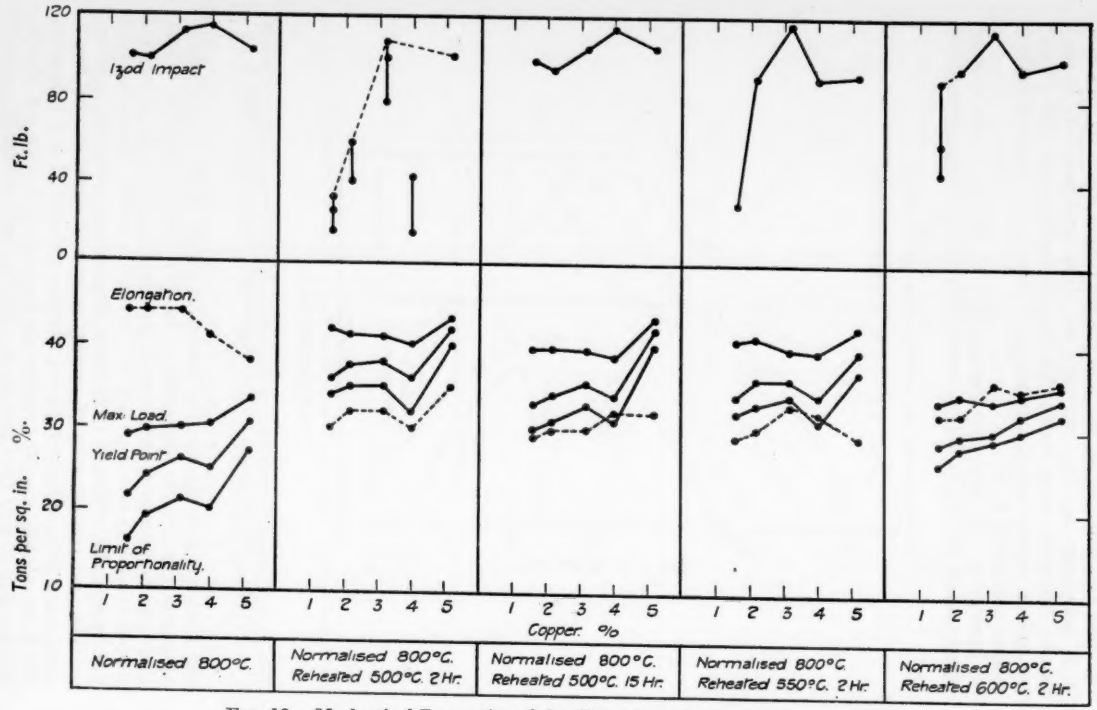

FIG. 13.—Mechanical Properties of the Chromium-Copper Steels Nos. 1–5.

tons per sq. in., elongation of 27% and Izod impact figure of 27 ft.lb. In the low-carbon series, the 2·0% copper steel gave a maximum load of 41·1 tons per sq. in., a yield point of 36 tons per sq. in., and an impact value of 91 ft.lb. A steel containing 0·88% of chromium and 4·0% of copper gave considerably better Izod impact values in the temper-hardened condition than a steel of similar composition but containing 0·47% of chromium. The Izod values of these two steels after normalising at 800° C. and reheating at 500–600° C. are given in Table VIII. With the higher-chromium steel, an impact figure of 43 ft.lb. was obtained in the fully temper-hardened conditions, as compared with only 18 ft.lb. for the steel containing 0·5% of chromium.

TABLE VIII.—*Effect of Chromium Content on the Izod Impact Figure of Temper-Hardened Steel.*

Steel No.	Composition. %.			Izod Impact Value. Ft.lb.				
				Air-Cooled from 800° C.	Air-Cooled from 800° C. and Tempered for—			
	C.	Cu.	Cr.		2 Hr. at 500° C.	15 Hr. at 500° C.	2 Hr. at 550° C.	2 Hr. at 600° C.
10	0·24	4·05	0·47	55	18	31	28	63
11	0·24	4·00	0·88	64	43	48	56	61

The tensile properties of steel No. 11 after normalising at 800° C. and reheating for 2 hr. at 500° C., which are given in Table IX., were only slightly better than those obtained with steel No. 10.

TABLE IX.—*Mechanical Properties of the* 4·0% *Copper,* 0·5–0·9% *Chromium Steels Nos.* 10 *and* 11, *Normalised at* 800° C. *and Reheated for* 2 *Hr. at* 500° *C. and Cooled in Air.*

Steel No.:	10.	11.
Chromium. %	0·47	0·88
Limit of proportionality. Tons per sq. in.	46·0	47·0
Yield point. Tons per sq. in.	49·0	49·5
Max. load. Tons per sq. in.	54·1	58·3
Yield Ratio	0·90	0·84
Elongation on 1·26 in. %	24	27
Reduction of area. %	55	60
Izod impact value. Ft.lb.	18	43

Oil-Hardened from 950° *C. and Tempered at* 500° *C. for* 3 *Hr.* (*Table X., Fig.* 14).—In both series, the maximum loads and yield points increased progressively with an increase in copper content. The Izod impact values tended to fall with an increase in the copper content, but there was no indication of scatter in the low-carbon

FIG. 13.—Mechanical Properties of the Chromium-Copper Steels Nos. 1–5.

series, and in the medium-carbon series the values were higher than those obtained after an initial cooling in air from 950° C.

TABLE X.—*Mechanical Properties of the Chromium-Copper Steels after Oil-Hardening from 950° C. and Tempering for 3 Hr. at 500° C.*

Treated in sections $1\frac{3}{4} \times \frac{1}{2}$ in. and 5 in. long.

Steel No.	Limit of Proportionality.	Yield Point.	Max. Load.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
	Tons per sq. in.							
1	37	44·0	46·6	0·85	29	65	48	232
2	41	44·0	50·4	0·87	27	62	33	253
3	42	47·5	53·3	0·89	26	64	35	266
4	41	50·0	57·4	0·87	25	62	30	290
5	44	53·5	59·3	0·90	25	60	24	282
6	45	53·5	61·9	0·86	21	55	26	312
7	51	58·0	65·3	0·88	21	53	37	322
8	52	63·5	68·5	0·92	19	51	21	338
9	56	67·0	71·4	0·93	18	51	21	350
10	55	67·0	71·5	0·93	22	53	28	339
11	58	68·0	72·2	0·94	17	47	18	343

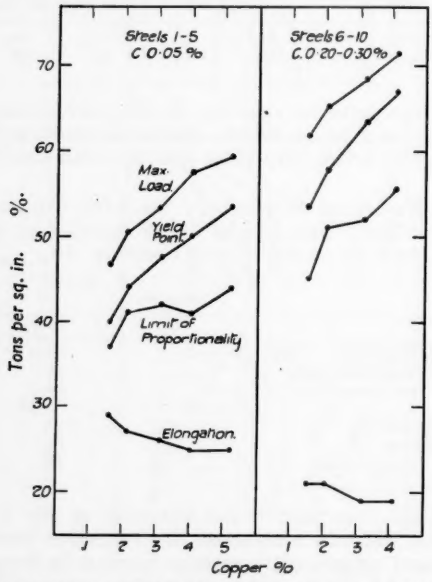

FIG. 14.—Mechanical Properties of Steels Nos. 1–10. Oil-Hardened from 950° C., tempered at 500° C.

Carbon 0·25–0·32%, *Chromium* 1·4%, *Copper* 2·0% (*Steels* 12 *and* 13).

Oil-Hardened from 900° *C. and Tempered for* 1 *Hr. at* 500–650° *C.* (*Table XI.*).—The mechanical properties of these steels in the oil-hardened and tempered condition were good and compared favourably with those obtainable in nickel-chromium steels. A comparison of their properties with those of the corresponding nickel-chromium-copper steel No. 21 (Table XV.) shows that when allowance has been made for the variations in carbon content (0·25–0·32%) no further improvement was obtained by the addition of 2·0% of nickel.

TABLE XI.—*Mechanical Properties of* 1·4% *Chromium*, 2·0% *Copper Steels Oil-Hardened from* 900° *C. and Tempered for* 1 *Hr. followed by Cooling in Air.*

Treated in sections $\frac{3}{4} \times \frac{3}{4}$ in. and 6 in. long.

Steel No.	Tempering Temperature. ° C.	Limit of Proportionality.	Yield Point.	Max. Load.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
		Tons per sq. in.							
12	500	61	73·6	78·5	0·94	16	46	16	359
	550	51	60·6	66·2	0·92	16	41	37	308
	600	41	53·2	59·6	0·89	22	59	65	277
	650	35	45·6	52·3	0·87	26	66	87	251
13	500	63	76·0	82·0	0·93	16	41	15	378
	550	55	64·2	70·5	0·91	18	50	28	327
	600	44	56·0	63·2	0·89	19	55	50	295
	650	40	49·2	56·1	0·88	22	59	73	266

Nickel-Copper Steels.

Carbon 0·30%, *Nickel* 2·2%, *Copper* 1·2–4·2% (*Steels* 14–16).

Normalised at 750–950° *C. and Reheated at* 500° *C.* (*Table XII., Fig.* 15).—After an initial normalising treatment at 750° C. followed by reheating at 500° C., a variation in the copper content between 1·0 and 4·0% had no effect on the mechanical properties of these steels, but after normalising at the higher temperatures air-hardening occurred and the tensile properties increased with an increase in the copper content. The Izod impact figure underwent a marked fall when the copper was increased from 1·0 to 2·0% and then remained approximately constant.

Oil-Hardened from 850° *C. and Tempered at* 500–600° *C.* (*Table XIII.*).—In the oil-hardened and tempered condition the maximum load, yield point and limit of proportionality increased with an increase in copper content, but the actual values obtained were again affected, as in the chromium steels, by variations in the

TABLE XII.—*Mechanical Properties of the Nickel-Copper Steels, Normalised and Reheated.*

Treated in sections $1\frac{1}{8} \times \frac{1}{2}$ in. and 5 in. long.

Steel No.	Limit of Proportionality.	Yield Point.	Max. Load.	Yield Ratio.	Elongation on 1·26 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
	Tons per sq. in.							
	Normalised at 750° C., Tempered 3 Hr. at 500° C.							
14	38	39·5	49·5	0·80	24	47	33	229
15	32	39·2	51·3	0·76	21	49	19	243
16	37	40·0	52·7	0·76	23	51	24	254
	Normalised at 800° C.							
14	29	34·0	44·7	0·76	32	58	45	206
15	37	43·5	55·1	0·79	20	38	13	264
16	45	52·5	62·5	0·84	21	49	13	297
	Normalised at 850° C., Tempered 3 Hr. at 500° C.							
14	41	42·5	51·8	0·82	25	47	23	235
15	45	47·5	58·6	0·81	22	38	12	272
16	47	53·0	61·8	0·86	21	43	15	291
	Normalised at 950° C.							
14	20	29·5	46·6	0·63	31	55	33	216
15	32	42·0	55·1	0·76	14	27	11	271
16	13	54·0	73·0	0·74	8	9	4	343
	Normalised at 950° C., Tempered 2 Hr. at 500° C.							
14	37	39·5	50·3	0·79	25	47	24	236
15	42	47·0	59·1	0·80	21	41	10	272
16	49	58·0	69·5	0·84	16	29	10	324

TABLE XIII.—*Mechanical Properties of the Nickel-Copper Steels after Oil-Hardening from 850° C. and Tempering for 2 Hr. at 500–600° C.*

Treated in sections $1\frac{1}{8} \times \frac{1}{2}$ in. and 5 in. long.

Steel No.	Limit of Proportionality.	Yield Point.	Max. Load.	Yield Ratio.	Elongation on 1·26 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
	Tons per sq. in.							
	Oil-Hardened from 850° C., Tempered 2 Hr. at 500° C. and Air-Cooled.							
14	46	50·0	59·4	0·84	23	55	41	288
15	58	59·5	68·2	0·87	21	47	21	333
16	68	76·0	77·0	0·99	18	41	14	361
	Oil-Hardened from 850° C., Tempered 2 Hr. at 550° C. and Air-Cooled.							
14	45	47·0	56·1	0·84	21	55	56	265
15	43	58·0	63·3	0·92	25	53	37	315
16	55	66·0	67·0	0·99	23	53	31	332
	Oil-Hardened from 850° C., Tempered 2 Hr. at 600° C. and Air-Cooled.							
14	36	39·0	47·4	0·82	29	65	59	226
15	40·5	42·0	50·3	0·84	19	55	52	248
16	49·5	56·0	57·2	0·98	21	58	47	282

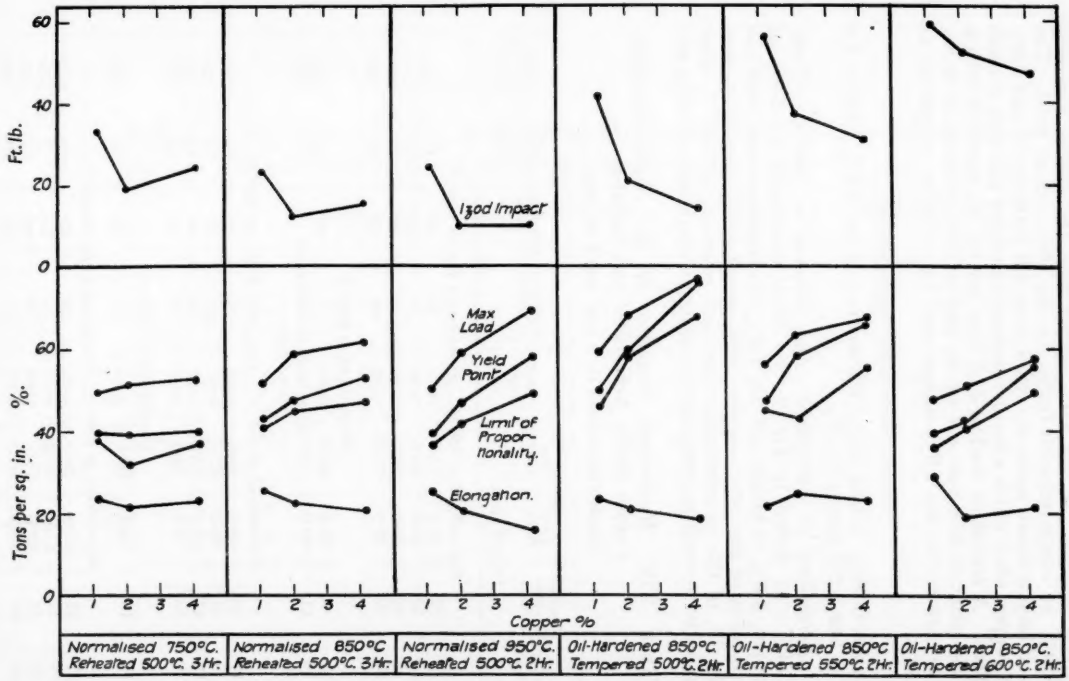

FIG. 15.—Mechanical Properties of the Nickel-Copper Steels Nos. 14–16.

carbon content. In the 4·0% copper steel the carbon was only 0·29%, as compared with 0·35% in the 2·0% copper steel. The Izod impact figure again showed a steep fall between 1·0 and 2·0% of copper, after which a further increase in copper had only a small effect. A maximum load of 63·3 tons per sq. in., together with a yield point of 58·0 tons per sq. in. and an Izod value of 37 ft.lb., was obtained in the 2·0% copper steel No. 15 after tempering at 550° C.

Nickel-Chromium-Copper Steels.

Carbon 0·30%, *Nickel* 2·0%, *Chromium* 0·6 *and* 1·2%, *Copper* 1·2 *and* 2·2% (*Steels* 17–21).

Normalised at 750–950° *C. and Reheated at* 500° *C.* (*Table XIV.*).—As shown in Fig. 7, the steels containing 1·0–2·0% of copper, 2·0% of nickel and 0·6–1·4% of chromium were, with the exception of the 1·0% copper, 2·0% nickel, 0·6% chromium steel No. 17, of the air-hardening type, and reheating at 500° C. after an initial normalising treatment produced a combined softening and

TABLE XIV.—*Mechanical Properties of the Nickel-Chromium-Copper Steels, Normalised and Reheated.*

Treated in sections $1\frac{1}{8} \times \frac{1}{2}$ in. and 5 in. long.

Steel No.	Limit of Proportionality.	Yield Point.	Max. Load.	Yield Ratio.	Elongation on 1·26 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
	Tons per sq. in.							
	Normalised at 750° *C., Tempered* 3 *Hr. at* 500° *C.*							
17	27	42·0	54·7	0·77	23	51	47	262
18	32	48·5	60·0	0·81	20	51	32	287
19	35	60·0	70·0	0·86	17	43	18	319
20	50	69·0	73·6	0·94	16	43	14	348
	Normalised at 800° *C.*							
17	8	33·5	61·3	0·55	17	22	13	276
18	11	40·0	Broke in head at 66·0 tons per sq. in.				8	337
	Normalised at 850° *C., Tempered* 3 *Hr. at* 500° *C.*							
17	40	48·0	58·8	0·82	21	51	20	284
18	47	59·5	67·8	0·88	21	47	14	321
19	47	62·5	70·6	0·89	18	43	14	337
20	58	74·0	79·0	0·94	16	45	12	375
	Normalised at 950° *C.*							
17	10	35·0	60·1	0·58	16	34	10	269
	Normalised at 950° *C., Tempered* 2 *Hr. at* 500° *C.*							
17	37	48·0	59·2	0·81	23	47	18	278
18	47	61·0	70·2	0·87	19	45	9	331
19	42	62·2	71·7	0·86	18	45	11	335
20	60	79·3	85·3	0·93	14	39	10	389

TABLE XV.—*Mechanical Properties of the 2% Nickel-Chromium-Copper Steels, Oil-Hardened and Tempered.*

Treated in sections $1\frac{1}{8} \times \frac{1}{2}$ in. and 5 in. long; No. 21, $\frac{3}{4} \times \frac{3}{4} \times 5$ in.

Treatment.	Oil-Hardened from 850° C. and Tempered 2 Hr. at—												Oil-Hardened from 900° C. and Tempered 1 Hr. at—			
	500° C.				550° C.				600° C.				500° C.	550° C.	600° C.	650° C.
Steel No. . .	17	18	19	20	17	18	19	20	17	18	19	20	21			
Chromium. % .	0·6	0·6	1·2	1·2	0·6	0·6	1·2	1·2	0·6	0·6	1·2	1·2	1·4			
Copper. % .	1·2	2·2	1·2	2·3	1·2	2·2	1·2	2·3	1·2	2·2	1·2	2·3	2·0			
Elastic limit. Tons per sq. in. .	55·0	66·0	60·0	62·0	51·0	56·0	52·0	55·0	44·5	47·5	47·0	49·0	62·0	49·0	44·0	38·0
Yield point. Tons per sq. in. .	66·5	70·6	72·0	76·0	60·0	63·0	63·5	66·0	49·7	53·3	53·0	55·5	73·4	61·6	54·6	48·4
Max. load. Tons per sq. in. .	71·4	76·3	77·9	81·5	65·2	68·2	69·5	71·1	56·8	59·8	60·7	62·1	79·5	68·4	62·2	56·5
Yield ratio . .	0·93	0·93	0·92	0·93	0·92	0·92	0·91	0·93	0·87	0·89	0·87	0·89	0·92	0·90	0·88	0·86
Elongation on 1·26 in. %. .	20	21	19	19	24	23	22	22	24	23	21	22	13	19	20	22
Reduction of area. % . . .	51	49	47	45	55	49	54	51	62	58	57	53	34	55	57	62
Izod impact value. Ft.lb. . .	21	13	13	11	30	23	15	13	50	43	29	26	17	35	57	72
Brinell hardness Number . .	350	366	372	396	324	329	334	350	274	291	294	296	371	319	298	266

temper-hardening effect. The mechanical properties were determined after cooling in air from temperatures between 750° and 950° C. followed by reheating for 3 hr. at 500° C.

Maximum loads of 55 to 85 tons per sq. in., according to the alloy content and treatment, were obtained, but, with the exception of steels Nos. 17 and 18 initially air-cooled from 750° C., the Izod impact figures were below 20 ft.lb.

Oil-Hardened from 850° C. and Tempered at 500–600° C. (Table XV.).—The properties obtained after oil-hardening from 850° C. and tempering at 500–600° C. are given in Table XV. The properties of steel No. 21, which received a slightly different heat treatment, are grouped together in the last panel of the Table.

The results show that a greater improvement was obtained by increasing the copper content than by increasing the chromium content in a 2·0% nickel, 0·6% chromium, 1·2% copper steel. High Izod values were obtained in steel No. 21, which had similar nickel, chromium and copper contents to steel No. 20, but had a very low manganese (0·18%) and a lower carbon content (0·28%); its properties did not, however, show any improvement over those of steel No. 17.

TABLE XVI.—*Mechanical Properties of the Nickel-Chromium-Copper Steels Nos. 22–25 after Oil-Hardening from 850° C. and Tempering for 2 Hr. at 500–650° C.*

Treated in sections $1\frac{1}{2} \times \frac{3}{4}$ in. and $4\frac{1}{2}$ in. long.

Steel No.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 2 in. %	Reduction of Area. %	Izod Impact Value. Ft.lb.	Brinell Hardness Number.
Oil-Hardened from 850° C., Tempered 2 Hr. at 500° C. and Air-Cooled.								
22	52	61·6	67·9	0·91	19	57	21	321
23	53	63·8	69·2	0·92	19	51	21	331
24	58	68·0	73·4	0·93	18	49	10	349
25	61	68·2	73·8	0·92	17	49	16	353
Oil-Hardened from 850° C., Tempered 2 Hr. at 550° C. and Air-Cooled.								
22	47	54·4	61·8	0·88	23	61	25	289
23	48	56·4	63·2	0·89	22	57	29	299
24	50	59·0	64·8	0·91	21	55	16	311
25	52	59·6	64·8	0·92	19	55	28	308
Oil-Hardened from 850° C., Tempered 2 Hr. at 600° C. and Air-Cooled.								
22	41	48·0	56·6	0·85	25	66	59	264
23	45	49·6	57·2	0·87	25	63	65	271
24	44	52·8	59·2	0·89	23	59	39	280
25	46	53·2	58·4	0·91	21	57	61	281
Oil-Hardened from 850° C., Tempered 2 Hr. at 650° C. and Air-Cooled.								
22	36	43·0	52·4	0·82	26	66	88	246
23	39	43·6	52·2	0·84	26	67	75	244
24	41	46·8	53·5	0·87	25	65	88	257
25	44	47·8	52·9	0·90	23	63	74	255

Carbon 0·27%, *Nickel* 3·5–0·0%, *Chromium* 0·9%, *Copper* 0·0–3·4% (*Steels* 22–25).

Oil-Hardened from 850° *C. and Tempered at* 500–650° *C.* (*Table XVI.*).—The effect on the mechanical properties of a progressive substitution of copper for the nickel in a 3·5% nickel, 0·9% chromium steel is shown by the results of tensile and Izod impact tests on these steels given in Table XVI.

The steels containing copper appeared to temper at a slower rate than the nickel steel, possibly owing to a temper-hardening effect, and after tempering at the lower temperatures (500–550° C.) increasing tensile properties were obtained with an increase in the copper content. At the higher tempering temperatures an increase in the limit of proportionality and yield point with an increase in the copper content was still obtained, but the maximum loads were the same for each steel. In all conditions the nickel-chromium steel without copper had the greatest ductility as measured by the elongation and reduction of area.

The microstructures were a normal sorbitic martensite with some ferrite, but the grain size in the copper-chromium steel No. 25 was much smaller than that in the three steels containing nickel. This effect of copper in producing a fine grain size was noted in all the microstructures examined.

The susceptibility to temper-brittleness of these steels is discussed later (Table XX.).

Mechanical Properties of Forgings 3¼ in. in Diameter.

Carbon 0·25–0·32%, *Nickel* 0·0–2·0%, *Chromium* 1·4%, *Copper* 2·0% (*Steels* 12, 13 *and* 21).

Normalised at 800° *C. and Normalised and Reheated at* 500° *C.*—These steels were intended for an examination of the effect of the size of section on the susceptibility to temper-hardening. Their alloy content was, however, sufficiently high to make them of the air-hardening type (*see* Fig. 9), and it was possible to ensure simple temper-hardening only in the larger sections of steels Nos. 12 and 13.

The mechanical properties obtained after normalising at 800° C. and after normalising and reheating for 2 hr. at 500° C. are given in Table XVII. Six-inch lengths, cut from the 3¼-in. dia. forgings, were annealed at 950° C., reheated at 800° C. and allowed to cool in still air. The reheating treatment at 500° C. was carried out on duplicate specimens after sectioning the normalised billets. Test-pieces were cut from the centre of the billets.

Temper-hardening was obtained in steels Nos. 12 and 13 in both the sizes examined, but the increase in hardness was appreciably greater in the smaller sections. The degree of air-hardening which occurred in the smaller sections of steels Nos. 12 and 13 after normalising at 800° C. was irregular and apparently dependent on small

TABLE XVII.—*Mechanical Properties of 2·0% Copper, 1·4% Chromium and 2·0% Copper, 2·0% Nickel, 1·4% Chromium Steels, Normalised at 800° C., and Normalised at 800° C. and Reheated at 500° C., in Sections 3¼ in. in dia. and ¾ or ½ in. Square.*

Steel No.:	12.				13.				21.			
Size of section as normalised:	3¼ in. dia.	¾ in. sq.	3¼ in. dia.	¾ in. sq.	3¼ in. dia.	¾ in. sq.	3¼ in. dia.	¾ in. sq.	3¼ in. dia.	¾ in. sq.	3¼ in. dia.	¾ in. sq.
Treatment:	N.*		R.*		N.*		R.*		N.*		R.*	
Limit of proportionality. Tons per sq. in.	12·0	27·0	27·0	40·0	18·0	12·0	28·0	41·0	12·0	12·0	40·0	49·0
Yield point. Tons per sq. in.	22·8	38·0	32·0	43·5	26·0	42·0	32·8	44·0	46·0	54·0	58·0	66·2
Max. load. Tons per sq. in.	40·0	52·2	46·4	54·5	43·2	72·1	48·1	58·2	75·8	91·2	69·7	72·4
Yield ratio	0·57	0·73	0·69	0·80	0·60	0·58	0·68	0·76	0·61	0·59	0·83	0·91
Elongation on 2 in. %	31	25	25	26	27	15	25	23	15	8	17	18
Reduction of area. %	63	63	57	62	57	28	54	57	35	22	42	47
Brinell hardness number	184	240	215	261	198	317	224	272	339	404	336	356
Size of section as normalised:	3¼ in. dia.	½ in. sq.	3¼ in. dia.	½ in. sq.	3¼ in. dia.	½ in. sq.	3¼ in. dia.	½ in sq.	3¼ in. dia.	½ in. sq.	3¼ in. dia.	½ in. sq.
Izod impact value. Ft.-lb.	55	14	23	19	43	12	21	9	16	17	14	20
Brinell hardness number	180	308	218	262	193	321	230	285	348	451	340	345

* N = Normalised at 800° C. R = Normalised and then reheated at 500° C.

TABLE XVIII.—*Mechanical Properties of 3¼-in. dia. Forgings, Air-Cooled from 850° C., Reheated for 2 Hr. at 500° C. and Air-Cooled. Effect of Copper.*

Steel No.	Composition. %					Centre of Forging.							Outside of Forging.						
	C.	Mn.	Cu.	Ni.	Cr.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.
26	0·30	0·45	...	...	...	11·0	16·0	30·3	0·53	35	55	31	15·0	17·0	31·0	0·55	36	58	29
27	0·27	0·60	1·06	...	...	30·0	32·0	42·3	0·76	29	51	19	33·0	34·5	43·5	0·79	27	51	17
28	0·26	0·62	...	1·40	...	21·0	24·0	35·1	0·68	35	58	54	22·0	24·0	35·6	0·67	37	58	50
29	0·26	0·72	1·0	1·49	...	32·0	33·2	43·6	0·76	29	52	30	36·0	37·0	45·1	0·82	30	53	31
30	0·27	0·66	...	1·54	0·61	26·0	28·0	42·6	0·66	31	58	43	28·0	29·3	43·1	0·68	31	60	49
31	0·31	0·70	1·02	1·36	0·48	37·0	40·5	52·2	0·78	24	51	19	41·0	42·0	52·4	0·80	27	53	18
32	0·30	1·21	...	...	...	21·5	24·0	37·1	0·65	37	58	48	24·5	25·0	37·8	0·64	35	60	43
33	0·27	1·48	1·05	...	...	35·5	37·0	47·9	0·77	28	51	33	36·0	38·5	48·7	0·79	28	51	28
34	0·29	1·90	1·0	...	...	37·0	40·0	55·5	0·72	21	43	17	41·5	43·0	55·1	0·78	25	51	21

TABLE XIX.—*Mechanical Properties of 3¼-in. dia. Forgings, Oil-Hardened from 850° C., Tempered for 2 Hr. at 600° C. and Air-Cooled. Effect of Copper.*

Steel No.	Composition. %					Centre of Forging.							Outside of Forging.						
	C.	Mn.	Cu.	Ni.	Cr.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.	Limit of Proportionality. Tons per sq. in.	Yield Point. Tons per sq. in.	Max. Load. Tons per sq. in.	Yield Ratio.	Elongation on 1·26 in. %.	Reduction of Area. %.	Izod Impact Value. Ft.lb.
26	0·30	0·45	...	...	...	17·0	21·0	32·8	0·64	34	62	59	22·0	23·0	34·2	0·67	36	65	51
27	0·27	0·60	1·06	...	...	30·0	32·0	42·0	0·76	25	51	29	30·0	31·7	43·0	0·74	21	55	38
28	0·26	0·62	...	1·40	...	23·0	24·0	36·4	0·66	32	64	65	25·0	26·0	37·3	0·70	35	64	65
29	0·26	0·72	1·0	1·49	...	33·5	35·0	43·9	0·80	31	58	40	35·0	36·3	44·6	0·81	30	57	40
30	0·27	0·66	...	1·54	0·61	31·0	33·0	45·3	0·73	24	55	40	33·0	36·5	47·1	0·78	27	55	48
31	0·31	0·70	1·02	1·36	0·48	38·5	41·5	52·2	0·80	22	49	35	43·0	44·5	52·9	0·84	22	53	30
32	0·30	1·21	...	...	...	24·0	25·5	37·7	0·68	34	62	46	27·0	27·5	38·6	0·71	34	60	45
33	0·27	1·48	1·05	...	...	33·5	34·5	44·5	0·78	25	49	29	34·0	36·0	45·3	0·79	21	55	31
34	0·29	1·90	1·0	...	...	38·5	42·8	53·2	0·80	18	43	15	43·0	46·0	54·7	0·84	24	45	20

variations in the conditions. Air-hardening occurred in both sizes in steel No. 21, and reheating at 500° C. had a normal tempering effect. A marked improvement in the tensile properties was obtained in all the steels as a result of the reheating treatment at 500° C., but the accompanying Izod impact values were low.

The Effect of 1·0% *of Copper in Carbon, Nickel and Nickel-Chromium Steels.*

The carbon, nickel, nickel-chromium and manganese steels Nos. 26–34 were forged to billets, 3¼ in. in dia., from ingots 4½ in. square. Three 6-in. lengths were cut from each forging for heat treatment, and tensile and Izod impact test-pieces were cut from the centre and outside of each length. The steels were tested in the following three conditions: As-forged and heated for 2 hr. at 500° C. and cooled in air; normalised at 850° C. and reheated for 2 hr. at 500° C. and cooled in air; and oil-hardened from 850° C. and tempered for 2 hr. at 600° C. and cooled in air.

The properties obtained in the normalised and reheated, and oil-hardened and tempered, conditions are given in Tables XVIII. and XIX. The results show that the addition of 1·0% of copper had a very marked effect on the properties of all the steels. It was greatest in the carbon steel in the normalised and reheated condition, where it produced an increase of 19 tons per sq. in. in the limit of proportionality, 16 tons per sq. in. in the yield point and 12 tons per sq. in. in the maximum load; it was least in the nickel-chromium steel, oil-hardened and tempered, where an increase of 7·5 tons per sq. in. in the limit of proportionality, 8·5 tons per sq. in. in the yield point and 7·0 tons per sq. in. in the maximum load was obtained.

Although the tensile properties of the 1·0% copper steel at the centre of the forging were appreciably better than those of the 1·5% nickel steel and approximated to those of the 1·5% nickel, 0·6% chromium steel, the Izod impact value of the copper steel was low in comparison. It is possible, however, that this could be improved by an increase in the copper content in conjunction with a higher tempering temperature or by the addition of a small amount of chromium.

The values obtained for the limit of proportionality, yield point, elongation and, particularly, the resistance to notched-bar impact were appreciably lower in the condition as-forged and reheated at 500° C. than in the normalised and reheated condition. The results are therefore not given in detail. In the steels containing copper the average Izod value, when the normalising treatment was omitted, was only 10 ft.lb., a minimum value of 3 ft.lb. being obtained in the high-manganese steel No. 30.

The tensile properties obtained on small sections, ¾ in. square, oil-hardened from 850° C. and tempered for 2 hr. at 600° C., were, in all the steels, practically the same as those obtained at the outside of the 3¼-in. dia. forgings after the same heat treatment.

Temper-Brittleness.

The susceptibility to temper-brittleness of the nickel-copper and nickel-chromium-copper steels Nos. 14–25 was measured in the usual way. Two test-pieces from each steel were oil-hardened from 850° C. and tempered from 2 hr. at 620° C. (650° C. for steels 22–25), one test-piece being cooled in water after tempering, and the other slowly, in the furnace, at 0·3° C. per min. The ratio of the impact figure of the material quickly cooled after tempering to that of the material cooled slowly was taken as a measure of the susceptibility to temper-brittleness.

The results obtained, which are given in Table XX., showed that the addition of up to 4% of copper did not induce temper-brittleness in a 2% nickel steel, and that the addition of up to 2% of copper to nickel-chromium steels, or the substitution of copper for nickel in nickel-chromium steels, appeared to have no effect on the susceptibility ratio.

Table XX.—*Effect of Copper on the Susceptibility to Temper-Brittleness of Nickel and Nickel-Chromium Steels.*

Steel No.	Composition. %					Impact Value. Ft.lb.		Susceptibility Ratio.
						O.H. 850° C., T. 620° C., and Cooled—		
	C.	Mn.	Ni.	Cr.	Cu.	In Water.	At 0·3° C. per min.	
14	0·32	0·55	2·2	...	1·2	69	62	1·1
15	0·35	0·46	2·2	...	2·1	55	50	1·1
16	0·29	0·51	2·3	...	4·2	55	47	1·2
17	0·30	0·55	2·1	0·63	1·2	59	21	2·8
18	0·31	0·52	2·1	0·61	2·2	54	17	3·2
19	0·33	0·62	2·1	1·2	1·2	50	7	7·1
20	0·34	0·60	2·2	1·2	2·3	45	9	5·0
22	0·30	0·44	3·5	0·9	...	96	18	5·3
23	0·27	0·38	2·6	0·8	1·0	84	22	3·8
24	0·26	0·44	1·6	0·9	2·0	92	16	5·8
25	0·27	0·43	...	0·9	3·4	76	32	2·4
						O.H. 900° C., T. 600° C., and Cooled—		
						In Air.	At 0·3° C. per min.	
12	0·25	0·24	...	1·5	2·1	65	24	2·7
13	0·32	0·23	...	1·4	2·1	50	20	2·5
21	0·28	0·18	2·2	1·4	2·0	57	22	2·6

The true susceptibility ratio was not determined for the 1·4% chromium, 2·0% copper steels (Nos. 12 and 13), but the ratio of the impact values of specimens cooled in air after tempering to those obtained after slow cooling, which are included in Table XX., showed that the susceptibility of these steels is of the same order as that of a chromium steel of similar composition but not containing copper.

Behaviour at High Temperatures.

Short-time tensile tests were carried out at 450° C. on the 0·5% chromium, 1·5–5·0% copper steels Nos. 1–11 after normalising at 800° and tempering at 500° C. The properties obtained are given in Table XXI., together with some results from two carbon steels and a 1-in. chromium-copper steel plate; these were tested in the as-rolled condition. The steels containing chromium and copper were greatly superior in tensile strength to the carbon steels, but a variation in the copper content between 1·5 and 5·0% did not appreciably affect the maximum load.

Scaling tests were made on ground and polished discs, 0·48 in. in dia. and 0·25 in. thick, in moist air at temperatures from 800° to 1000° C. The steels containing chromium and copper scaled to a less extent than plain carbon steels, but no difference in behaviour was noted with a variation in the copper content between 1·5 and 5·0%.

Table XXI.—*Short-Time Tensile Tests at 450° C.*

Composition. %.			Max. Load. Tons per sq. in.	Elongation on 1·26 in. %.	Reduction of Area. %.
C.	Cr.	Cu.			
0·12	...	...	17·1	56	82
0·05	0·5	1·6–5·2	28·6–29·1	22–28	36–49
0·24	...	...	22·8	44	65
0·28	1·1	0·3	34·8	25	53
0·20–0·29	0·5	1·5–4·1	35·4–37·0	28–33	59–62
0·24	0·88	4·0	36·9	30	63

Conclusions.

The properties of some nickel, chromium and nickel-chromium steels containing 1–5% of copper have been examined with special reference to their susceptibility to temper-hardening.

Temper-Hardening.—The maximum increase in hardness on tempering was usually obtained by reheating at temperatures between 450° and 550° C. after air-cooling from 800° C., the time necessary to reach the maximum hardness being longer the lower the temperature. An increase in carbon content from 0·05 to 0·29% in steels containing 0·5% of chromium reduced the increase in

hardness obtainable by temper-hardening. In these steels the maximum increase in tensile properties, produced by tempering at 500° after air-cooling from 800° C., was obtained in the presence of 1·5% of copper. Additional copper up to 4% produced no further temper-hardening effect. The notched-bar impact figure of the steels temper-hardened at 500° C. was low or irregular, but considerably better values were obtained, with a slight sacrifice of tensile strength, when temper-hardening was carried out at 550° C. The properties of temper-hardened 2·0% nickel copper steels were slightly inferior to those of the 0·5% chromium copper steels.

An increase of copper content up to the maximum examined (4%) produced a marked increase in the limit of proportionality, yield point and maximum load of the medium-carbon steels containing 0·5% of chromium normalised at 800° C. The effect was not so pronounced in the low-carbon steels. The susceptibility to air-hardening increased with an increase in copper content and with an increase in normalising temperature, and was observable at lower normalising temperatures in small bars than in larger sections. In the absence of air-hardening, the degree of temper-hardening was not affected by variations in normalising temperature between 800° and 1000° C., but some degree of air-hardening greatly assists in securing good properties which result from the simultaneous occurrence of the softening effect of reheating at 500° C. and the hardening effect of copper precipitation.

Oil-Hardening and Tempering.—The steels were also examined in the oil-hardened and tempered condition. Even after quenching in oil from 950° C. the main effect of reheating a steel containing 0·05% of carbon and 0·5% of chromium was to induce temper-hardening. The properties, as oil-hardened and tempered, of the medium-carbon steels containing chromium or nickel in addition to copper were generally improved by an increase in the copper content above the 1·5% necessary to give maximum temper-hardening. It appears that part at least of the nickel of such steels may be replaced by a similar weight of copper without detriment to the properties in the oil-hardened and tempered condition. Copper appeared to be without influence in increasing or reducing the susceptibility to temper-brittleness.

Comparison of the Two Methods of Treatment.—The chief advantage of temper-hardening is the simplicity of the treatment, which, however, can only be secured at the sacrifice of some of the properties attainable. The results recorded in this paper afford a comparison of the properties of copper-bearing steels obtainable by utilising ordinary quenching and tempering or by employing the temper-hardening process, and show that in sections up to $3\frac{1}{4}$ in. in dia. the advantage lies with the ordinary method of hardening and tempering. This treatment is essential for obtaining high tensile strength. An argument for the temper-hardening treatment is that

it should minimise the mass effect, but this advantage does not apply in sections of moderate size, since copper itself has a beneficial effect in increasing the depth of quench-hardening. By temper-hardening alone, without the aid of some air-hardening in normalising, a tensile strength of over 50 tons per sq. in. is not easy to get. For moderate tensile strength the two treatments may be adjusted to give the same hardness and maximum load. In these conditions of equal hardness the tensile properties, including the elongation and reduction of area, are similar, but the notched-bar impact figure is invariably considerably lower in the temper-hardened steel.

The author wishes to acknowledge his indebtedness to Mr. C. F. Marks, B.Sc., who prepared most of the steels, and to Mr. E. S. Spencer-Timms, B.Sc., who carried out the thermal analyses; he also wishes to express his gratitude to Dr. R. H. Greaves for his continuous interest and advice.

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CORRESPONDENCE.

Dr. N. P. ALLEN (Birmingham) wrote that Mr. Harrison's paper described a very thorough and painstaking piece of work, and that one could completely agree with his conclusion that the advantages of the precipitation-hardening treatment of copper-containing steels were not so great as to endanger materially the position of the established quenched and tempered alloy steels.

In considering the value of copper as an alloying element in quenched and tempered steels, it was possible to doubt whether tensile and hardness tests, especially when they were carried out on steels made by laboratory processes on a small scale, and when the heat-treated blanks had, as a rule, been small, provided sufficient data to support every conclusion which had been reached.

It was common knowledge that, considered from the point of view of the tensile properties obtained on small pieces, many compositions of alloy steels were found which could be considered as coming within a given range of tensile strength. The choice between them, for a given application, generally depended upon some property or combination of properties, such as ease of manufacture, behaviour in forging, machinability, reliability, uniformity or reproducibility. Account had also to be taken of segregation or the liability to give brittleness and cracks under certain conditions. These properties often figured largely in the ultimate cost of the article under consideration, though at first sight they might seem trivial. A modification of the composition which produced an improvement in one direction all too often resulted in a more than equivalent deterioration in some other direction. Thus, in the case of the substitution of copper for nickel in nickel-chromium steels, a slight gain in the yield ratio was offset by a fall in the elongation and a tendency to a deterioration of the hot-working properties.

The copper-containing steels, had, however, another limitation. In many applications an important attribute of the alloy steel employed was its deep-hardening capacity and freedom from distortion as a result of the mild quenches which could be used. These properties depended upon the velocity of transformation of austenite into ferrite and carbide which took place at sub-critical temperatures, generally between 650° and 400° C., and which must be prevented during the quenching operation to allow martensite to be formed. Ineffective quenching, it was well known, gave inferior properties after tempering. Consequently, steels having a low velocity of transformation in this temperature range were desired.

Some attention had recently been paid to the measurement of the transformation velocity, which could be made with a fair degree of accuracy by dilatometric methods.

Figs. A and B contained some results bearing upon the question

of the substitution of copper for nickel, and related to steels of the under-mentioned compositions :

Mark.	Carbon. %	Chromium. %	Nickel. %	Copper. %
A	0·28	0·67	3·70	...
B	0·28	0·69	2·61	1·11
C	0·23	0·80	1·64	2·09
D	0·26	0·69	...	3·65

The measurements were made at a constant temperature of 625° C., which was close to the temperature at which the decomposition of austenite into ferrite and pearlite was most rapid. The results obtained at other temperatures were similar in general form.

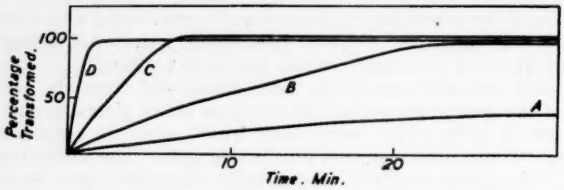

FIG. A.—Transformation Curves at 625° C.

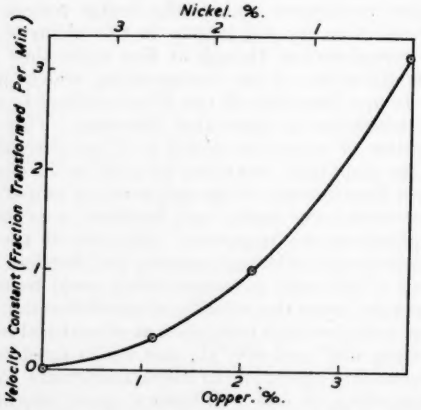

FIG. B.—Effect on Transformation Velocity at 625° C. of Substitution of Copper for Nickel in Steels containing 0·3% of carbon, 0·7% of chromium and 3·7% of nickel plus copper.

Fig. A gave the actual transformation curves, and the calculated velocity constants were plotted against the nickel or copper contents

in Fig. B. It would be seen that in the copper-free steel the transformation was very slow, and therefore easily suppressed, and that as nickel was progressively replaced by copper, the velocity of transformation increased in a striking manner. The transformation of the nickel-free steel was complete in a very short time. A comparatively vigorous quench would be required to harden a steel of this kind. The replacement of nickel by copper was therefore accompanied by an important loss of deep-hardening capacity, which loss should be carefully taken into account in considering the merits of copper-containing steels.

The author's paper raised a perhaps not unimportant question of nomenclature. There had clearly been difficulty in distinguishing between the " temper-hardening " effect, and the softening generally produced by " tempering." The author was in some places (for example, in the synopsis and on p. 317) obliged to speak of " normal tempering " when he was referring to the changes giving the usual softening effect, which suggested that the term " temper-hardening " contained in itself some germ of confusion. It appeared that consideration should be given to the possibility of finding a more suitable and, if possible, universally acceptable term for this treatment and phenomenon.

AUTHOR'S REPLY.

Mr. HARRISON wrote, in reply, that it was appreciated that many factors other than the mechanical properties obtainable in test-pieces prepared under laboratory conditions must be considered before a suggested composition could be regarded as an alternative to existing steels. It was felt, however, that on the basis of the results obtained on the steels described in the paper, the use of copper as an alloy element in steel was worthy of serious consideration.

Dr. Allen's results on the effect of additions of copper on the velocity of transformation of austenite into ferrite and carbide were extremely interesting. The largest sections treated during the investigation were only $\frac{3}{4}$ in. thick, and these were, of course, fully hardened after quenching in oil, but some results of Brinell hardness tests made on small sections cooled at various rates from above Ac_3 showed that at an intermediate rate of cooling of 4° C. per sec., the nickel-chromium steel No. 22 was more fully hardened than the copper-chromium steel No. 25. The difference in hardness numbers obtained—450 to 400 Brinell—was not, however, so great as might have been expected from Dr. Allen's curves, and it would be interesting to know how these curves should be interpreted in terms of the size of section which could be hardened throughout.

The author agreed with Dr. Allen that it was desirable to find some universally acceptable term for the phenomenon described in

the paper as "temper-hardening." It was a matter which had given rise to discussions from time to time without a satisfactory conclusion having been reached. The confusion in the present instance lay in the exact meaning to be applied to the word "tempering." This was commonly associated with the idea of softening, but there were a number of instances in which the tempering treatment—that was, a reheating treatment to some temperature above the atmospheric but below the critical range—resulted in either no change or an increase in hardness. "Temper-hardening" had been used because the maximum hardening effect was obtained at temperatures normally used in the "tempering" of steel and to emphasise that such treatment might, in the case of copper-containing steels, produce an increase in hardness. A new term for this heat treatment, without reference to the effect produced, was required or, preferably, "tempering" should be re-defined.

MARTENSITIC GRAINS IN RAPIDLY-COOLED INGOT IRON AND MILD STEEL.*

By B. JONES, M.Sc., F.I.C. (University College, Cardiff), and N. GRAY, M.Met. (Port Talbot).

(Figs. 9 to 38 = Plates XXIII. to XXVI.)

Synopsis.

Two ingot irons and a mild steel were cooled at different rates from controlled temperatures, including the critical range; the mechanical properties were determined and the results correlated with the microstructures. There is a well-defined range of temperature in both ingot iron and mild steel which produces a marked embrittlement on quenching from these temperatures. Low impact values found in mild steel rapidly cooled from temperatures coinciding with the Ac_1 point and above it are due to the presence of martensitic grains, the characteristics of which are illustrated and discussed. Reference to the work of other investigators is given. The brittle range in rapidly cooled ingot iron occurs only in the upper temperature range of the ferrite-austenite zone of the equilibrium diagram, and is confined to temperatures of 875–900° C. Martensitic areas formed by quenching from temperatures lower than these do not cause embrittlement. This is due to the relatively small volume of austenite formed before quenching. Heating to the temperature range stated results in the spreading of the austenite areas, and on rapid cooling the martensitic areas formed are spread over a larger area and by dissociation interfere with the grain boundaries of the ferrite, giving rise to very low notched-bar impact values. A more precise explanation for the peculiar structures found by other workers in rapidly-cooled ingot iron is given.

A complete analysis of the materials used is given, including gases and non-metallic inclusions. An Appendix describes the method used for the determination of oxygen. The main features include the solution of the steel in molten aluminium in a reducing atmosphere, using apparatus readily available in a steelworks laboratory. The results obtained, even on killed steels, compare favourably with those produced by the more expensive method of hot extraction *in vacuo*.

In spite of the voluminous literature on the heat treatment of such widely-used materials as ingot iron and mild steel, the authors found, some years ago, that certain peculiar microstructures obtained in these rapidly-cooled materials were difficult to interpret, and, moreover, in some instances were associated with definite embrittlement. Many of the structures could not readily be correlated either with any particular range of temperature to which the iron or steel had been heated, or with the rate of cooling.

This information was not only required from a technical

* Received February 23, 1938.

standpoint, but the matter also assumed some practical importance when the firm with which one of the authors is associated was called upon to supply an order of mild-steel plate to a specification which included a normalising treatment on a test bar, followed by quenching in water from a temperature of 700° C. This test specimen was then subjected to a temper bend test, and the specification required that it should withstand being doubled over, either by pressure or by blows from a hammer, without fracture until the internal diameter was not greater than one and a half times the thickness of the test-piece and the sides were parallel. In an attempt to meet the specification, tests carried out gave variable results, and in many cases failure of the test bar occurred by cracking. A preliminary series of experiments was carried out, which included the heating of mild-steel plates, of bend-test size, to various temperatures within the critical range of the steel, and, after quenching them in water, subjecting them to the standard bend test. Results showed that after quenching from temperatures between 700° and 750° C., the specimens broke in a very brittle manner by sudden fracture, in some instances just after the former was applied. Both the rolled and normalised plate, after quenching from 650° C., bent satisfactorily in the test over an angle of 180°.

Curious microstructures are also found in ingot iron after quenching from various temperatures, as described by Brooke and Hunting,[2] Desch,[4] Cameron,[10] and Whiteley.[15] As it was desirable to know the effects of rapidly cooling these low-carbon materials from various temperatures, it was decided to heat them under strictly controlled conditions to temperatures which included the critical range, and, after quenching them in different sizes to vary the rate of cooling, to carry out tensile, hardness, and notched-bar impact tests, correlating these with a microscopical examination. These tests were carried out on the materials which had been analysed for the usual constituents and for gases and inclusions. A search in the literature, when these experiments were planned, did not give the required information, although much work on the quenching of steels had been described in various technical journals during the past forty years.

The cause of the well-known brittle range found in ingot iron when hot-worked in a certain range of temperature between approximately 800° and 900° C. is still not known, although Brooke and Hunting [2] showed that a "eutectoid" was formed in the iron quenched from below 900°. The object of these experiments was not, however, to investigate the cause of the hot-shortness of the iron, as it could not be expected that the exact conditions operating at these temperatures could be accurately retained, even by very rapid cooling. Nevertheless, it was anticipated that, in view of the peculiar structures found in ingot iron after rapid cooling from certain temperatures, a correlation of the microstructures with the physical properties, including notched-bar impact values, would

give interesting results. There does not appear to be any satisfactory investigation dealing with these features.

Many authors have included work on the quenching of mild steel [3, 5, 8, 12, 14, 16] since the investigation by Arnold and McWilliam.[1] Much valuable work in recent years has been carried out by Sir H. C. H. Carpenter and Robertson on the structures obtained on heating and cooling various steels at different rates.[9] Whiteley has published his investigations on the quenching of steels[7] and of Armco iron.[15]

These papers did not, however, supply the authors with the information required, namely, various physical properties of the materials correlated with the microstructures after rapid cooling from controlled temperatures. On the other hand, Bleakney[12] obtained low Izod impact values with a mild steel after quenching; from temperatures within the critical range, and discussed the microstructures with special reference to heat treatment applied to case-hardening; the mechanical properties were not determined. Lea and Arnold[14] have published the results of their tests on the embrittlement of low-carbon steels after quenching them from temperatures up to 900° C., together with tests on age-embrittlement. These results, although they did not deal with ingot iron, were very instructive and germane to the problem in hand. Owing to the absence of microscopical tests, however, and the fact that most of the tensile tests were carried out on small specimens in a Hounsfield tensometer, this paper did not give the required data. The authors hope therefore that, in spite of much published work, the results of their experiments on ingot irons and mild steel may be of interest.

Materials.

The tests were carried out on ingot iron, a copper-titanium ingot iron, and a mild steel. The chemical analyses are given in Table I.

Table I.—*Chemical Analyses of the Materials.*

Material.	Mark.	C. %	Si. %	Mn. %	S. %	P. %	Cu. %	Ni. %	Ti. %	N_2. %
Ingot iron .	*G.*	0·020	0·002	0·048	0·044	0·013	0·065	0·049	Nil	0·006
Ingot iron .	*B.*	0·020	0·002	0·050	0·040	0·012	0·300	0·049	0·011	0·005
Mild steel .	*W.*	0·15	0·050	0·560	0·038	0·027	0·066	0·051	Nil	0·008

Material.	Mark.	Inclusions. %	Composition of Inclusions.					O_2.* %	Calculated Total O_2 from Inclusions. %
			SiO_2. %	Al_2O_3. %	FeO. %	MnO. %	TiO_2. %		
Ingot iron .	*G.*	0·3370	0·0022	0·0036	0·3250	0·0062	Nil	0·070	0·075
Ingot iron .	*B.*	0·3673	0·0019	0·0014	0·3530	0·0100	0·0010	0·072	0·080
Mild steel .	*W.*	0·1361	0·0095	0·0040	0·1150	0·0076	Trace	0·025	0·033

* By method described in Appendix.

It was considered desirable to obtain as complete an analysis as possible, as the influence of gases, non-metallic inclusions, &c., has mostly been ignored in previous investigations of this nature, and it is considered by some that they may have important effects on certain properties. This is especially of importance in the case of ingot iron, in which a high oxygen content and a large number of oxide inclusions are features of the material.

The oxygen content was determined by the method described in the Appendix. The method, which includes some new features, gives results in many instances comparable with those obtained by the more expensive method of hot extraction *in vacuo*. The materials

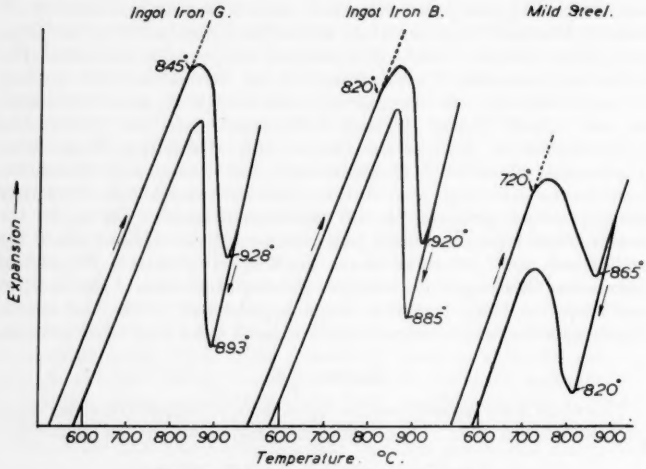

FIG. 1.—Heating and Cooling Curves.

were rolled from selected billets from ingots of basic open-hearth steel which represented standard production. The billets were rolled down to a round bar $1\frac{1}{8}$ in. in dia., and, after cutting up into convenient lengths, each bar was analysed. The chemical composition was found to be very constant. The critical range of the materials was determined dilatometrically, and is illustrated in Fig. 1. The bars were normalised prior to quenching, the ingot irons from 940–950° C., and the mild steel from 890–900° C.

METHOD OF HEATING AND QUENCHING.

The bars were heated in a special wire-wound vertical electric furnace having a uniform heating length of 8 in. The furnace was

supported on a stand, so that a large quenching tank of water could be placed under it when required. The bar was supported from the top by a thick nichrome wire, and a platinum/platinum-rhodium thermocouple was placed at the centre of the bar. The tip of the couple was bare, to minimise any lag, and the temperature was measured and controlled by a Cambridge automatic potentiometric controller. The furnace had a drop bottom to facilitate quenching, which enabled the bars to be quenched almost instantaneously from the heat-treatment temperature.

As information was required from a works standpoint on the quenching of the materials in the unmachined condition, tests were carried out on the quenched $1\frac{1}{8}$-in. round bars. In addition, the rate of cooling was increased by quenching bars of reduced section. The latter were machined to a size slightly greater than that required for subsequent testing. The tensile test bar before quenching was turned to approximately 0·82 in. in dia. in the centre, whilst the bar for the notched-bar impact test was milled to a section of approximately 12 mm. before quenching. This allowed for the removal of any oxidised surfaces when machining to the size of the standard test bars required. The temperature range investigated was 650–1000° C. The bars were put into a warm furnace and heated slowly to the required temperature. They were soaked for a period which allowed the heat to penetrate the specimen, namely, 1 hr. for the unmachined bar, and 30–40 min. for the bars of reduced section. The pyrometer was then withdrawn, the bottom of the furnace was dropped, and the quenching tank was run under the furnace tube. The bars were dropped into the water immediately, and were continuously moved up and down until they were cool enough to be handled. The cooling rates from 650–1000° C. were as follows:

		Time taken to Cool from Quenching Temp.	Average Rate of Cooling.
Tensile bars.	$1\frac{1}{8}$-in. round bar.	$15\frac{1}{2}$–38 sec.	41–26° C. per sec.
	Reduced section.	$8\frac{1}{2}$–19 ,,	76–52° C. ,, ,,
Impact bars.	$1\frac{1}{8}$-in. round bar.	$15\frac{1}{2}$–38 ,,	41–26° C. ,, ,,
	Reduced section.	3–11 ,,	216–95° C. ,, ,,

The scaling of the bars was kept at a minimum, as there was little chance for air to enter the furnace. A little lump charcoal helped to reduce oxidation.

Tests after Quenching.

The tensile test was carried out on a bar machined to B.S.S. test-piece *D*, namely, 0·798 in. in dia. and 3 in. gauge length. This size was considered to represent the type of material being tested better than one of smaller dimensions, as ingot iron is of a rimming nature, and a test on the bar machined to the core would represent only the more impure portion of the material.

The impact test bars were milled to a thickness of 10 mm. Four test-pieces of standard size, 60 × 10 × 10 mm., were tested from each quenched bar. The standard Izod 45° notch was used, two notches being milled on the outer portion, and two on the inside portion of the bar, the average of those four tests being taken. The tests were carried out in a 30-kg.m. Charpy machine.

Hardness tests were carried out on the quenched bars from which the impact specimens were obtained, and as it was desirable to obtain hardness readings on parts of the bar representing both the outer and the inner portions, the hardness was measured by means of a Firth hardometer, using a 2-mm. ball under a load of 120 kg. At least four indentations were made on each bar, and the average of these was recorded. The complete testing of the quenched bars was carried out in duplicate.

Microscopical examinations were made on the notched-bar impact test-piece.

In all cases the tensile, impact and hardness tests were carried out at a standard time of three days after quenching. The tests do not include those on ageing, although, as shown by Lea and Arnold [14] and others, quench-age-embrittlement occurs in the lower range of temperatures.

TABLE II.—*Quenching of Ingot Iron G. Mechanical Properties.*

Quenching Temp. ° C.	Size of Bar. R.S. = Reduced Section.	Limit of Proportionality. Tons per sq. in.*	Yield Stress. Tons per sq. in.†	Max. Stress. Tons per sq. in.	Elongation on 3 in. %	Reduction of Area. %
As normalised	1⅛-in. round bar	8·2	9·0	21·2	42·0	70·8
650	1⅛-in. round bar	9·0	10·5	22·2	43·0	70·5
	R.S.	7·2	10·7	22·6	43·0	69·9
700	1⅛-in. round bar	9·7	10·8	22·7	41·5	67·5
	R.S.	5·7	11·1	22·7	40·5	68·9
730	1⅛-in. round bar	9·5	11·0	22·7	41·2	67·8
	R.S.	5·7	11·0	23·5	41·0	69·0
760	1⅛-in. round bar	9·6	11·0	23·0	40·7	67·1
	R.S.	6·5	11·1	22·8	41·0	67·0
800	1⅛-in. round bar	9·4	11·5	23·0	41·5	66·2
	R.S.	5·4	11·0	22·6	41·5	69·2
825	1⅛-in. round bar	9·4	11·2	22·8	41·0	65·0
	R.S.	6·4	11·2	22·8	39·8	66·9
850	1⅛-in. round bar	9·5	10·9	22·5	40·7	63·0
	R.S.	7·4	11·7	23·0	39·7	64·0
900	1⅛-in. round bar	10·2	11·4	22·9	39·5	61·3
	R.S.	6·2	12·3	23·7	39·5	67·6
950	1⅛-in. round bar	9·3	11·5	22·7	37·5	59·8
	R.S.	7·1	11·8	22·8	36·5	65·8
1000	1⅛-in. round bar	9·7	12·0	22·9	38·0	57·5
	R.S.	5·6	12·0	22·4	36·0	62·7

* Ewing extensometer. † Load giving 0·2% permanent set.

Results of Experiments.

(1) *Ingot Irons.*

The tensile test results are given in Tables II. to V., and in Figs. 2 to 5. They show a remarkable indifference to the effects of quenching, the yield stress, maximum stress and the ductility remaining almost constant. The maximum stress for ingot iron *G* does not vary more than about 2 tons per sq. in. even in the more rapidly quenched bars, while the increase in ingot iron *B* is only approximately 4 tons per sq. in. The latter material possesses greater strength than ingot iron *G*, and the limit of proportionality and yield stress are somewhat higher. The limit of proportionality in both ingot irons is reduced as the quenching rate is increased. The abnormal feature, however, in both materials is shown in the impact test results. Whilst there is a slight, although definite fall in impact value on quenching from approximately 700–800° C., there is a narrow temperature range of 875–900° C. in which extremely low values are obtained in the bars of reduced section (Figs. 2 to 5).

Table III.—*Quenching of Ingot Iron* G. *Charpy Impact Value and Hardness.*

Quenching Temp. ° C.	Size of Bar. R.S. = Reduced Section.	Charpy Impact Value (Average).		Hardness Number (Average).
		Kg.m.	Ft.lb.	
As normalised	1½-in. round bar	18·94	137	101
650	1½-in. round bar	19·35	140	110
	R.S.	18·25	132	115
700	1½-in. round bar	19·91	144	113
	R.S.	18·80	136	112
730	1½-in. round bar	17·14	124	117
	R.S.	17·00	123	120
760	1½-in. round bar	17·23	125	120
	R.S.	16·72	121	119
800	1½-in. round bar	19·63	142	111
	R.S.	18·52	134	118
825	1½-in. round bar	18·50	134	110
	R.S.	18·80	136	121
850	1½-in. round bar	17·42	126	109
	R.S.	18·66	135	118
875	1½-in. round bar	9·81	71	108
	R.S.	1·49	10·8	117
900	1½-in. round bar	7·92	57·3	120
	R.S.	0·83	6·0	130
925	1½-in. round bar	13·00	94	120
	R.S.	14·51	105	130
950	1½-in. round bar	17·14	124	122
	R.S.	15·90	115	132
1000	1½-in. round bar	13·13	95	125
	R.S.	12·43	90	131

TABLE IV.—*Quenching of Ingot Iron* B. *Mechanical Properties.*

Quenching Temp. ° C.	Size of Bar. R.S. = Reduced Section.	Limit of Proportionality. Tons per sq. in.*	Yield Stress. Tons per sq. in.†	Max. Stress. Tons per sq. in.	Elongation on 3 in. %	Reduction of Area. %
As normalised	1⅛-in. round bar	12·8	14·0	21·3	43·5	75·0
650	1⅛-in. round bar	9·6	12·7	23·0	39·5	68·4
	R.S.	5·6	11·8	23·6	39·0	69·0
700	1⅛-in. round bar	12·8	13·5	23·4	39·5	67·6
	R.S.	8·7	14·5	25·2	34·0	65·6
730	1⅛-in. round bar	12·3	13·8	24·0	39·0	67·0
	R.S.	8·5	15·4	25·3	38·0	66·2
760	1⅛-in. round bar	11·5	13·0	24·0	42·0	69·6
	R.S.	7·0	13·0	24·5	38·0	67·1
800	1⅛-in. round bar	12·0	13·4	24·0	40·0	67·9
	R.S.	7·5	13·3	24·2	40·0	67·9
825	1⅛-in. round bar	11·8	13·2	24·0	39·0	66·5
	R.S.	7·7	13·7	24·4	39·0	66·0
850	1⅛-in. round bar	11·6	12·8	24·0	38·0	65·6
	R.S.	8·0	14·0	24·5	38·5	66·0
900	1⅛-in. round bar	13·7	13·8	24·5	34·5	65·0
	R.S.	6·7	13·8	25·0	33·0	62·5
950	1⅛-in. round bar	13·6	14·8	23·9	37·0	64·7
	R.S.	6·0	14·0	25·3	37·0	61·5
1000	1⅛-in. round bar	14·0	14·9	24·2	34·3	62·4
	R.S.	5·0	14·8	25·6	33·0	62·0

* Ewing extensometer. † Load giving 0·2% permanent set.

The materials are tough when quenched from 850° C., and also from 950° C., whilst intermediate values are obtained from a temperature of 925° C. Above 950° C. the impact values again decrease slightly, owing to the effect of grain growth. This sudden embrittlement of ingot iron by quenching from these temperatures was surprising, and there does not appear to be any reference to it in the metallurgical records.

Ingot iron *B* is tougher than *G* on quenching from most temperatures, but both give very low impact results in the brittle range, that of *G* being only 0·83 kg.m. (equivalent to 6 ft.lb.) on quenching from 900° C. The rate of cooling is important in producing the brittle condition, as such a low value is not obtained on quenching the 1⅛-in. round bars. There appears to be no correlation with any other property, as the ductility of the irons is not abnormal. The brittle impact test-pieces have a coarsely " crystalline " fracture, while the others are usually unbroken and fibrous in character.

Microscopical Examination.—A selection of micrographs of ingot irons *B* and *G* after water-quenching are reproduced in Figs. 9 to 17.

Both ingot irons contained appreciable quantities of oxide inclusions, but the grain size of the copper-titanium material was

TABLE V.—*Quenching of Ingot Iron* B. *Charpy Impact Value and Hardness.*

Quenching Temp. °C.	Size of Bar. R.S. = Reduced Section.	Charpy Impact Value (Average).		Hardness Number (Average).
		Kg.m.	Ft.lb.	
As Normalised	1⅛-in. round bar	25·57	185	106
650	1⅛-in. round bar	20·25	146	119
	R.S.	19·35	140	129
700	1⅛-in. round bar	20·25	146	124
	R.S.	18·03	130	127
730	1⅛-in. round bar	19·00	137	127
	R.S.	18·66	135	131
760	1⅛-in. round bar	18·25	132	130
	R.S.	20·04	145	132
800	1⅛-in. round bar	24·05	174	117
	R.S.	19·35	140	128
825	1⅛-in. round bar	23·00	166	118
	R.S.	20·74	150	133
850	1⅛-in. round bar	21·85	158	113
	R.S.	19·77	143	128
875	1⅛-in. round bar	10·37	75	113
	R.S.	1·37	9·9	128
900	1⅛-in. round bar	14·24	103	128
	R.S.	6·24	45·2	139
925	1⅛-in. round bar	17·28	125	125
	R.S.	17·0	123	140
950	1⅛-in. round bar	22·78	172	127
	R.S.	22·12	160	142
1000	1⅛-in. round bar	22·12	160	129
	R.S.	17·83	129	147

smaller. Many peculiar structures were found in the quenched bars, and, in fact, the rapidly-cooled bars from each temperature could be made the subject of a study of the different structures found. Such characteristics as the doubling of the grain boundaries, the presence of ghostly white areas near the grain boundaries, &c., are features generally assumed to be associated with a high oxygen content. Straight markings across the grains resembled Neumann lamellæ, whilst many twin-like grains of ferrite were observed. On quenching ingot iron *G* from 825° C. a dark-etching constituent appeared as threads at the grain boundaries. At 830° C. there was distinct evidence of another phase, which increased in amount as the quenching temperature was raised. This was due to the formation of γ-iron, as shown by Cameron,[10] and by Whiteley.[15] Figs. 9 to 11 show the structures obtained in the ingot irons rapidly-cooled from 850° C. The structures are definitely martensitic, and represent areas in which the γ-iron solid solution of carbon had changed to α-iron. Quenching from 875° C. produces a larger volume of the martensitic areas, owing to the spreading of the

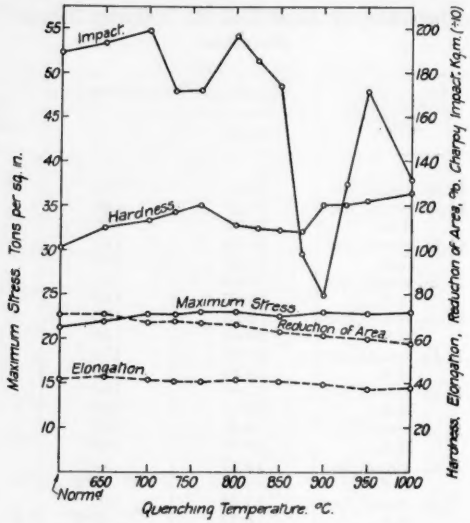

FIG. 2.—Quenching of Ingot Iron G; $1\frac{1}{8}$-in. round bars.

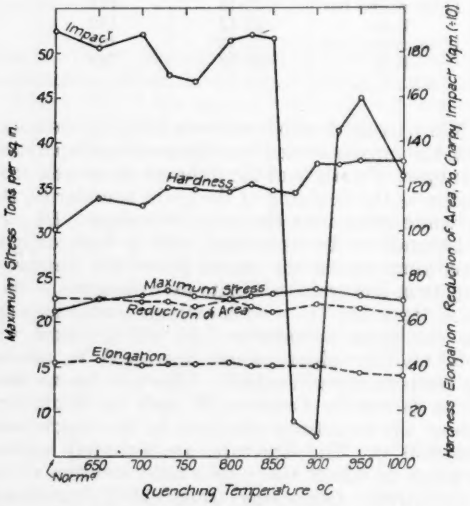

FIG. 3.—Quenching of Ingot Iron G; bars of reduced section.

austenite by absorption of ferrite, and typical structures are shown in Figs. 12, 13, 14 and 16.

Heating to 900° C. and quenching gave the structures shown in Figs. 15 and 17, and, although they do not, at first sight, resemble the martensitic structure described above, they are undoubtedly formed from austenitic areas which had diffused through the metal to an appreciable extent. Many areas are formed on quenching from 900° C. (and also from 875° C. in the ingot iron *B*) which

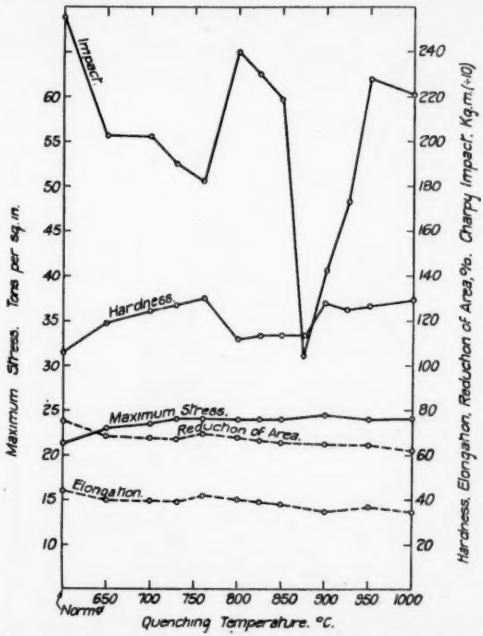

FIG. 4.—Quenching of Ingot Iron *B*; 1½-in. round bars.

are characterised by parallel wavy lines and a splitting up of the grain boundaries. Quenching from 925° and 950° C. does not produce such a localised structure of wavy lines, owing to the conversion of all the metal to γ-iron. This results in a uniform distribution of the carbon, and gives a comparatively even structure on quenching. Soaking at a temperature of 1000° C. produces grain growth, but there are no abnormal features in the quenched material.

Discussion of Results.—The only information on the correlation of mechanical properties with microstructures in quenched ingot

iron is that given by Brooke and Hunting,[2] who found a so-called "eutectoid," stated to consist of carbide, sulphide and phosphide, on quenching from temperatures between approximately 900° and 800° C. This constituent is evidently similar to that produced in these tests by heating to and quenching from temperatures above 800° C., and it is undoubtedly martensitic in character, as suggested by Whiteley.[15] Whilst the tensile properties of ingot iron were examined by Brooke and Hunting, the reduction of area and hard-

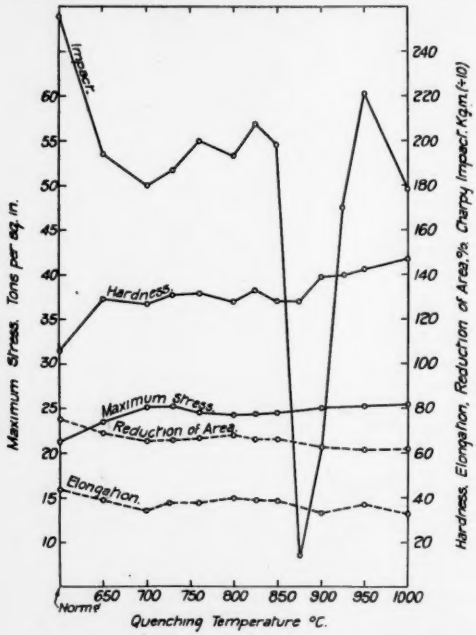

FIG. 5.—Quenching of Ingot Iron *B*; bars of reduced section.

ness values were not recorded, and tests for embrittlement were not carried out. In the discussion of the paper, and elsewhere,[4] Desch suggested that the structures found in quenched ingot iron were due to nitrogen, and that his experiments had confirmed this view. Hatfield, in the discussion of Brooke and Hunting's paper, stated that a low impact value was obtained on quenching Swedish wrought iron from 850° C. Quenching tests on small specimens of the ingot irons showed that γ-iron areas first appear in *G* at 830° C. and in *B* at 800° C., as shown by the presence of martensitic grains. The

lowering of the α–γ transformation by the alloy additions in the latter is also indicated in the dilatometer heating curves in Fig. 1. The temperatures found by quenching, however, are slightly lower than those obtained by a continuous rate of heating, owing possibly to the fact that a certain amount of the γ phase must be formed before its presence is made evident. The martensitic structure persists on quenching from 875° C., and the coarse acicular pattern produced is due to the low carbon content of the original austenite areas.

It is extremely unlikely, in the authors' opinion, that the structures found are due to nitrogen, in view of the low nitrogen content of the materials (0·005–0·006%), and is more likely to be due to carbon, as, in fact, theory demands. Whiteley [15] has shown that

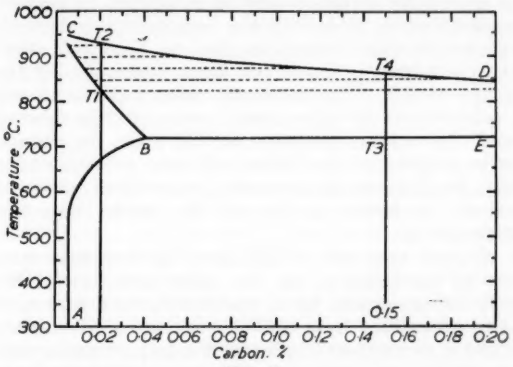

FIG. 6.

the martensitic areas can be produced in pure iron without nitrogen by the introduction of a little carbon, and he has stated that the simulated eutectoid appearance of the constituent found by Brooke and Hunting is mainly the result of the partial decomposition of the γ-iron areas in the early stages of quenching when they pass through the temperature range in which they are highly unstable. The authors agree with this view. Some of the structures, such as that reproduced in Fig. 10, show that, although the acicular martensitic structure is formed, the interlacing material is composed of finely deposited particles. In other structures this is not evident. Embrittlement of the notched bars was not evident on quenching from a temperature of 850° C. but only from 875° and 900° C. The well-defined martensitic structures illustrated were not found in the same degree on quenching the $1\frac{1}{8}$-in. round bars, whilst the lowest impact results were obtained on the more rapidly cooled bars.

Reference to the iron-carbon equilibrium diagram for low-carbon steels reveals some interesting features. Fig. 6 has been constructed

from the results of the authors' experiments and from data for commercial iron and steels published by Köster,[8] Whiteley,[15] and others, and represents the phases at various temperatures on heating ingot irons and mild steels. On heating ingot iron, the carbide is retained in solid solution in ferrite at a temperature where the composition line cuts *AB*. Austenite areas formed at 830° C. increase in volume continuously up to 928° C., as indicated by *T*1 and *T*2. The line *CB* is therefore related to the eutectoid line *BE* in that it denotes the formation of γ-iron solid solution of carbon. The authors refer to it as the "ac_1" point to distinguish it from the Ac_1 point of pearlitic steels, and it represents the incipient change from α-iron solid solution to γ-iron solid solution. The latter, in both ingot iron and mild steel, forms martensitic grains on quenching. The γ-iron is most rich in carbon at the lower temperature, as shown by the composition indicated by the horizontal dotted line drawn to the Ac_3 line *CD*, the carbon content of the ferrite ground-mass being indicated by the corresponding line to *BC*. The austenitic areas increase in volume as the Ac_3 temperature is approached, owing to the absorption of ferrite, and the carbon concentration becomes progressively less. The relative lengths of the horizontal lines on either side of the composition line indicate the increasing quantity of austenite formed as the amount of ferrite is reduced, the latter being completely absorbed at 928° C.

Both in ingot iron and in mild steel the austenitic areas grow in volume by spreading along the grain boundaries, the growth presumably being assisted by a concentration of carbon near the latter. On quenching from 850° C. the areas of martensite are not sufficiently numerous to influence the impact properties, but on heating to 875° C. the amount of austenite increases appreciably and is of a lower carbon concentration (approximately 0·12%). This austenite, on quenching, produces dilute martensite, which is spread over a considerable area of the grain boundaries and gives rise to a very low notched-bar impact value (Figs. 3 and 5).

That the character of the grain boundary is affected in some of the grains is shown by the presence of many jagged edges (Fig. 14). In some grains the entrapped carbides are retained as parallel plates by the decomposition of austenite at the grain boundary (Fig. 16). At 900° C. the average carbon content of the austenite is very low (approximately 0·05%) owing to rapid diffusion, and, on quenching, the types of structure illustrated in Figs. 15 and 17 are found. These are the structures referred to in the literature which have been difficult to interpret. These experiments show, however, that they are caused by the decomposition of austenite of such a low carbon content that acicular patterns are formed from the grain boundaries. Martensitic grains, which are caused by quenching austenite of a higher carbon content, are not formed, and the effect of rapid cooling is to cause a "buckling" of the

grain boundaries in many areas. This effect occurs on quenching *B* from 875° C. The grain boundary disturbance undoubtedly assists the propagation of a crack, as is shown by the extremely low notched-bar impact value. At temperatures above Ac_3 the carbon content of the austenite is more uniformly distributed, recrystallisation occurs, and a high impact value is again attained on quenching from 950° C. The unusual structures found on rapidly cooling ingot iron from 875–900° C. can therefore be explained by the carbon content of the metal, and the evolution of the unusual structures obtained has been traced. The high oxygen content of the metal does not, apparently, influence the structures. This is due to the fact that oxygen is present mainly as solid oxide inclusions (Table I.), which, in spite of the large number, allows the full effect of 0·02% of carbon to be shown.

The authors do not feel justified, from the results of these experiments, in giving an explanation for the brittle range of ingot iron at high temperatures. It is generally considered to be due to effects produced by sulphur when present in amounts greater than that which can be fixed as manganese sulphide, but this has not been definitely proved. It would be an unwise speculation to attribute the hot-brittleness to the effect of the carbon content alone, when other elements such as sulphur, manganese, copper, nickel and oxygen are each present in much greater amounts. It is a coincidence, nevertheless, that the brittle zone found on hot-rolling occurs in the $\gamma + \alpha$ zone of the equilibrium diagram, namely, between approximately 900° and 800° C. At temperatures below the Ar_3 point, large amounts of ferrite are being formed in the presence of a rapidly lessening amount of austenite of low carbon content. It is speculative whether, owing to the rapid movement of the austenite at the grain boundaries, and to its change of carbon content in this range of temperature, the grain boundaries are sufficiently disturbed to cause cracking of the metal on rolling. The authors hope to carry out more work on the cause of the brittle zone. It may be mentioned that the hot-shortness is not revealed by hot impact tests, as shown by the work of Greaves and Jones.[6]

(2) *Mild Steel.*

The tensile results are given in Table VI. and the impact and hardness tests in Table VII., while the graphs shown in Figs. 7 and 8 were obtained from these. The yield stress and maximum stress increase as the quenching temperature is raised, and the increased rate of cooling affects these results appreciably. An increase of 13–15 tons per sq. in. in the maximum stress is obtained by quenching bars of reduced section at temperatures greater than 950° C.

A sudden increase in tensile strength is found on quenching from 730° C., *i.e.*, at the Ac_1 point, and this coincides with the formation of hard martensitic grains. A slight decrease in tensile strength

TABLE VI.—*Quenching of Mild Steel* W. *Mechanical Properties.*

Quenching Temp. °C.	Size of Bar. R.S. = Reduced Section.	Limit of Proportionality. Tons per sq. in.*	Yield Stress. Tons per sq. in.†	Max. Stress. Tons per sq. in.	Elongation on 3 in. %	Reduction of Area. %
As normalised	1⅛-in. round bar	17·5	18·0	27·6	38·0	65·4
650	1⅛-in. round bar	15·1	17·7	28·8	37·5	65·3
	R.S.	9·2	16·6	29·6	36·0	64·9
700	1⅛-in. round bar	17·0	17·9	28·8	36·5	65·3
	R.S.	9·6	18·8	31·1	33·7	64·9
730	1⅛-in. round bar	13·8	17·8	34·9	30·0	61·0
	R.S.	9·4	22·3	38·9	24·7	48·0
760	1⅛-in. round bar	13·0	18·1	35·0	30·0	60·5
	R.S.	7·6	21·4	40·0	21·0	41·0
800	1⅛-in. round bar	13·7	18·2	32·4	32·0	66·3
	R.S.	8·3	22·0	41·5	15·0	42·0
825	1⅛-in. round bar	12·4	18·0	32·0	31·0	66·5
	R.S.	7·2	20·4	37·4	19·0	56·5
850	1⅛-in. round bar	15·6	21·6	33·5	35·5	68·5
	R.S.	9·2	23·2	38·9	25·2	65·7
900	1⅛-in. round bar	15·4	22·4	34·6	27·0	66·0
	R.S.	8·4	25·5	41·5	20·0	51·3
950	1⅛-in. round bar	14·2	23·0	35·0	25·5	61·5
	R.S.	8·4	31·0	48·6	14·8	34·0
1000	1⅛-in. round bar	12·1	23·0	37·3	24·5	61·0
	R.S.	7·6	33·8	52·5	9·0	20·0

* Ewing extensometer. † Load giving 0·2% permanent set.

TABLE VII.—*Quenching of Mild Steel* W. *Charpy Impact Value and hardness.*

Quenching Temp. °C.	Size of Bar. R.S. = Reduced Section.	Charpy Impact Value (Average).		Hardness Number (Average).
		Kg.m.	Ft.lb.	
As normalised	1⅛-in. round bar	17·23	125	131
650	1⅛-in. round bar	12·30	89	142
	R.S.	11·33	82	148
700	1⅛-in. round bar	7·05	51	145
	R.S.	3·48	25·3	160
730	1⅛-in. round bar	3·13	22·7	161
	R.S.	1·16	8·4	203
760	1⅛-in. round bar	1·69	12·2	179
	R.S.	1·44	10·4	216
800	1⅛-in. round bar	2·53	18·3	172
	R.S.	2·21	16·0	207
825	1⅛-in. round bar	12·89	93·2	161
	R.S.	3·87	28·0	198
850	1⅛-in. round bar	19·09	138	167
	R.S.	5·19	37·5	185
900	1⅛-in. round bar	18·29	132	171
	R.S.	6·4	46	210
950	1⅛-in. round bar	9·40	68	190
	R.S.	2·91	21	232
1000	1⅛-in. round bar	3·55	25·7	201
	R.S.	1·80	13·0	286

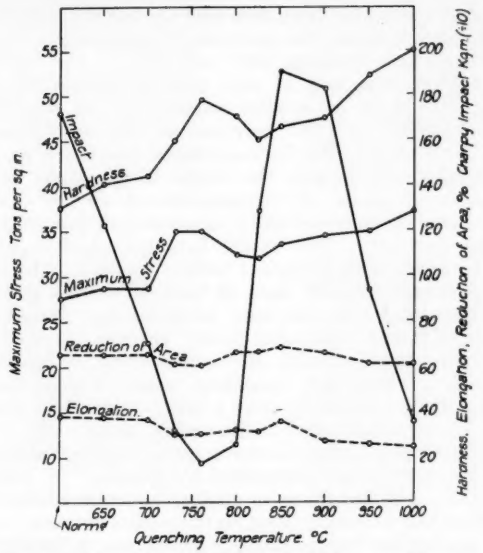

FIG. 7.—Quenching of Mild Steel; 1½-in. round bars.

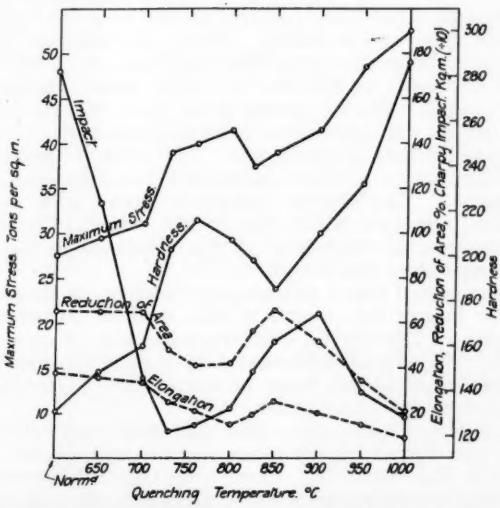

FIG. 8.—Quenching of Mild Steel; bars of reduced section.

then occurs on quenching from 800–825° C., but a gradual increase again takes place on raising the quenching temperature. Within the range of temperature between 700° and 825° C., the ductility, as measured by the reduction of area and elongation, is reduced, especially in the bars of smaller section, but is regained at a temperature of 850° C. The hardness of the steel is raised on quenching from above 700° C., reaching a maximum at 760° C., when a decrease sets in and the shape of the curve is in line with the maximum stress. At temperatures above 850° C. the more rapid rate of cooling increased the tensile strength progressively and reduced the ductility. The tensile bars quenched rapidly from 950–1000° C. broke with a typical brittle fracture. In the early experiments tensile tests on bars of reduced section gave erratic results on quenching from the same temperature. More consistent results were obtained only after much practice in rapid cooling and by reducing to a minimum the scaling effects on heating. The formation of a thin hard tenacious scale, which would not dislodge readily on quenching, gave a lower tensile test than when the metal surface was exposed to the cooling water.

The abnormal impact test results on quenching from above 700° C. confirmed the brittle range described by Bleakney [12] and by Lea and Arnold.[14] The slower rate of cooling, however, when quenching the $1\frac{1}{8}$-in. bars had a definite effect on the results obtained, especially those for the higher temperatures. There was a sudden loss of impact value on quenching from temperatures near the Ac_1 point, the lowest values being found for 730° C. in the bars of reduced section; this minimum value occurred at 760° C. in the $1\frac{1}{8}$-in. bars, owing to the slower rate of cooling. The impact value of the latter again increased progressively on quenching from above 800° C. and reached a maximum at 850–900° C., above which another rapid decrease occurred. The toughening of the $1\frac{1}{8}$-in. bars on quenching from 825–900° C. was remarkable, and was appreciably greater than that found in the bars of smaller size. Above 900° C. grain growth and the formation of a coarse martensitic structure again caused embrittlement. The impact test-pieces broke with a bright "crystalline" fracture within the brittle range. The fractures revealed the gradual toughening of the specimens as the critical range of temperature was passed.

The tests proved that a serious embrittlement, as shown by the notched-bar impact test, occurs in mild steel on quenching from temperatures of 730–800° C., even when the rate of quenching is not rapid. The effect is accentuated by a more vigorous quench. The embrittlement in this range of temperature is also shown in the bend test, as previously stated.

Microscopical Examination.—The microstructures found in the quenched steel revealed many interesting features. Some of these are shown in Figs. 18 to 35. There is no visible difference in the structure until a temperature of 700° C. is reached, when the character

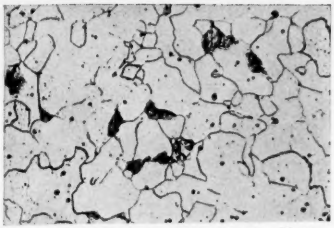

FIG. 9. Ingot Iron *B*, W.Q. 850° C. Martensitic grains. × 100.

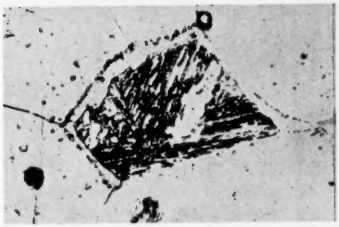

FIG. 10.—Ingot Iron *G*, W.Q. 850° C. Martensitic grain with double boundary. × 500.

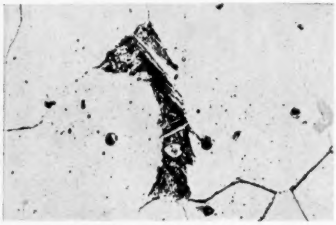

FIG. 11.—Ingot Iron *B*, W.Q. 850° C. Martensitic grain around grain boundary. × 350.

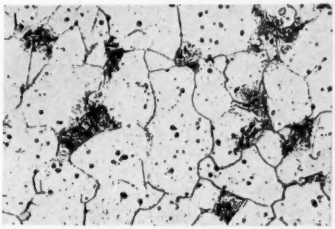

FIG. 12.—Ingot Iron *G*, W.Q. 875° C. Diffusion of martensite. × 100.

FIG. 13.—Ingot Iron *G*, W.Q. 875° C. × 350.

FIG. 14.—Ingot Iron *B*, W.Q. 875° C. × 350.

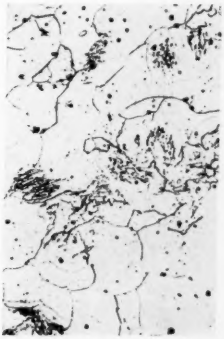

FIG. 15.—Ingot Iron *G*, W.Q. 900° C. × 100.

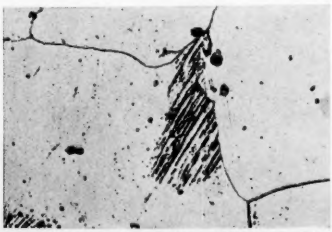

FIG. 16.—Ingot Iron *B*, W.Q. 875° C. × 350.

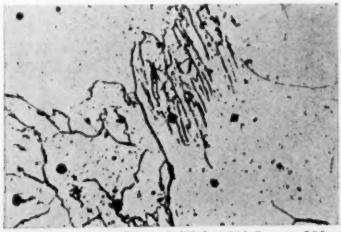

FIG. 17.—Ingot Iron, *G*, W.Q. 900° C. × 350.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jones & Gray.*

[*To face p.* 344 P.

Plate XXIV.

Microstructures of Mild Steel on Quenching from various Temperatures. × 100.

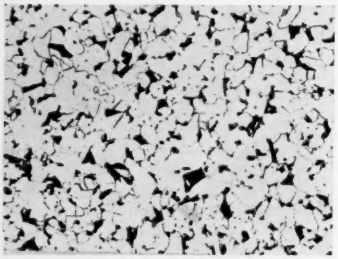

Fig. 18.—As Normalised.

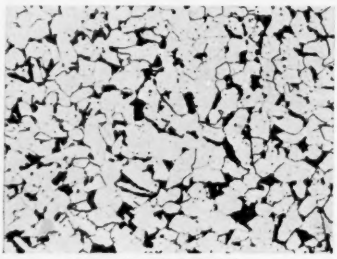

Fig. 19.—W.Q. 700° C.

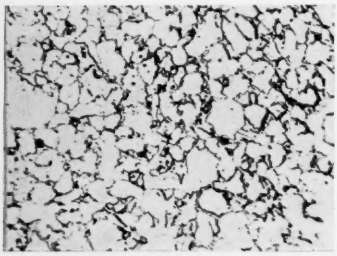

Fig. 20.—W.Q. 730° C.

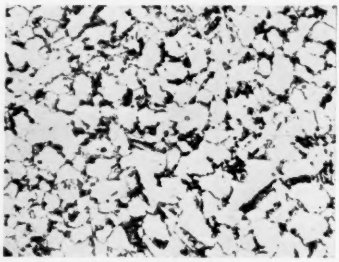

Fig. 21.—W.Q. 760° C.

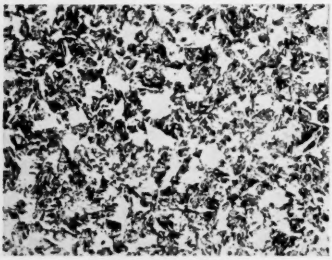

Fig. 22.—W.Q. 800° C.

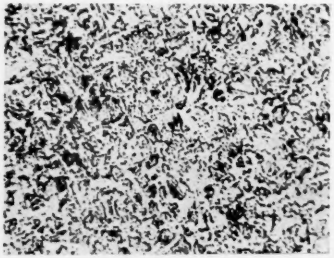

Fig. 23.—W.Q. 850° C.

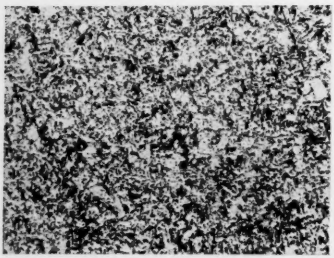

Fig. 24.—W.Q. 900° C.

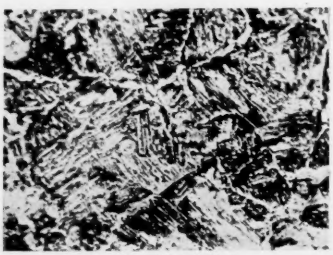

Fig. 25.—W.Q. 950° C.

[*Jones & Gray.*

MICROSTRUCTURES OF MILD STEEL ON QUENCHING FROM VARIOUS TEMPERATURES.

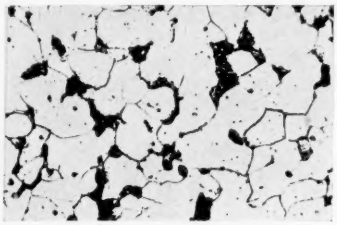

FIG. 26.—As Normalised. × 350.

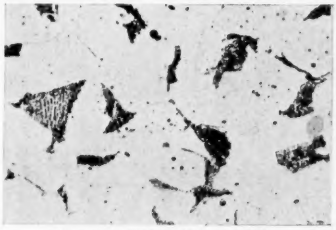

FIG. 27.—W.Q. 700° C. × 350.

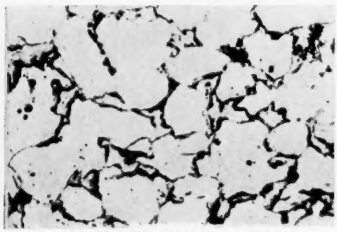

FIG. 28.—W.Q. 730° C. × 350.

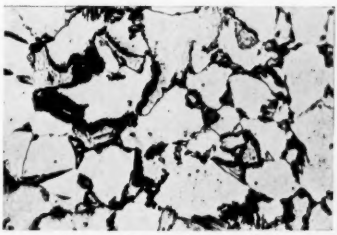

FIG. 29.—W.Q. 760° C. × 350.

FIG. 30.—W.Q. 770° C. × 500.

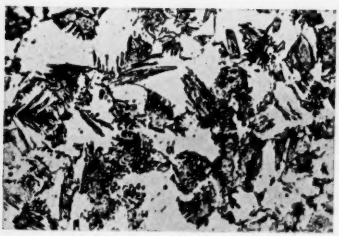

FIG. 31.—W.Q. 800° C. × 350.

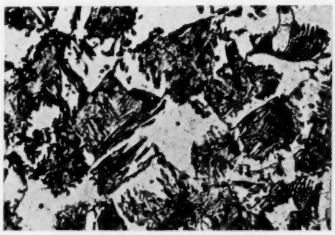

FIG. 32.—W.Q. 800° C. × 500.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jones & Gray.*

MICROSTRUCTURES OF MILD STEEL ON QUENCHING FROM VARIOUS TEMPERATURES.

FIG. 33.—W.Q. 850° C. × 350.

FIG. 34.—W.Q. 900° C. × 350.

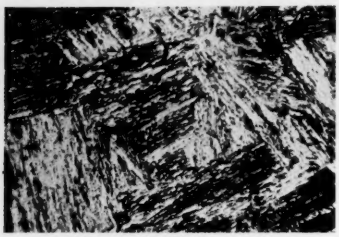

FIG. 35.—W.Q. 1000° C. × 350.

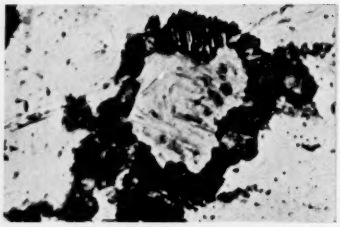

FIG. 36.—Martensitic Grain with Border of Troostite. × 1000.

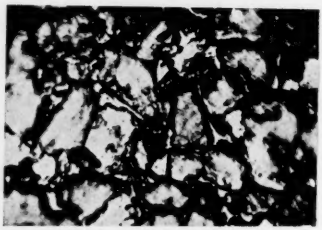

FIG. 37.—Mild Steel, W.Q. 730° C. Strongly etched. Bright martensitic cores. × 350.

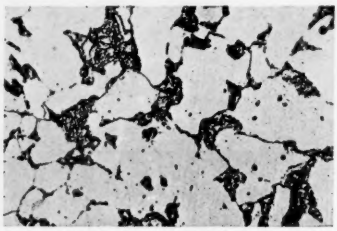

FIG. 38.—Mild Steel, W.Q. 730° C., T. 600° C. Martensitic grains sorbitised. × 350.

(Micrographs reduced to two-thirds linear in reproduction.)

[*Jones & Gray.*
[*To face p.* 345 P.

of the pearlite grains begins to change owing to a coalescence, as shown in Fig. 27. This causes a decreased impact value. The pearlite grains are completely changed, however, on heating to 730° C., and the austenite formed is converted into almost structureless martensitic grains on quenching from this temperature. The martensite is surrounded by a band of troostite as shown in Figs. 20 and 28. The troosto-martensite areas formed by the slower rate of cooling are shown in Fig. 36. Deep etching in nitric acid reveals the bright martensitic cores shown in Fig. 37. The martensitic areas formed on quenching from 730–760° C. form an almost continuous network around the ferrite grains, and this type of structure corresponds to maximum embrittlement found in the impact test. At temperatures above 730° C. the austenite increases in volume by the absorption of ferrite, and, on quenching, a brown-etching structureless type of dilute martensite is formed. Quenching from 800–825° C. results in the formation of martensitic areas characterised by sharp angular boundaries, as seen in Figs. 31 and 32. The troostite border is absent from structures produced at temperatures above 800° C. This "dog-tooth" type of martensite is associated with a low notched-bar impact value. Heating to 850° C. results in the absorption of most of the ferrite, and, on rapid cooling, the low-carbon austenite transforms into areas of dilute martensite surrounded by ferrite boundaries (Figs. 23 and 33). At 900° C. the absorption of ferrite is complete, and, on quenching, the dark-etching homogeneous structure shown in Fig. 24 is produced. Owing to the low carbon content of the steel, however, the suppression of ferrite is not complete (Fig. 34). Overheating the steel to 1000° C. produces a coarse acicular martensitic structure on rapid cooling, as shown in Fig. 35. The steel has a low impact value. The many different structures found in rapidly-cooled mild steel (Figs. 18 to 35) bear no resemblance to the original normalised structure.

Discussion of Results.—The brittle range of temperature found in rapidly-cooled mild steel described by Pulsifer,[11] Bleakney [12] and Lea and Arnold [14] has been confirmed. These experiments show, however, that the rate of quenching from the temperatures investigated influences the results appreciably. Although the tensile strength and ductility of a mild steel are affected to some extent on quenching from the brittle range of temperature between approximately 700° and 800° C., serious embrittlement is shown by both the standard bend test and the notched-bar impact test. This is due to the presence of hard martensitic grains formed around the grain boundaries. The critical range in the steel between the Ac_1 and Ac_3 points is shown in Figs. 1 and 6. The lowest notched-bar impact result occurs after quenching from a temperature just above $T3$, *i.e.*, at 730° C., where the hardness of the martensitic grains is greatest, owing to its high average carbon content (approximately 0·85%). The carbon content of the austenite becomes progressively less as it approaches $T4$, as indicated by the

horizontal lines drawn to the Ac_3 line, and, on rapid cooling, the martensite produced contains less carbon and is comparatively soft. Even with the more rapid rate of quenching, the martensitic grains formed at 730–760° C. were bordered with a narrow band of troostite, showing that both the Ar′ and Ar″ change points occurred on cooling. Soaking the steel at 730° C., *i.e.*, just above Ac_1, at which temperature the austenite contains an average carbon content approaching the eutectoid composition, results in the formation of a border where the carbon content is lower than that of the interior of the grains, owing to absorption of the adjacent ferrite. There is a " contour line " of carbon concentration, enclosing a region in which the rate of cooling was sufficient to depress the change point of the high-carbon core to Ar″. In the lower-carbon borders of the austenite the change point occurs at a higher temperature, at Ar′, producing troostite. It is possible that, on the other hand, the expansion of the austenite grains during the $\gamma \rightarrow \alpha$ martensitic change at Ar″ may cause pressure effects at the austenite-ferrite boundaries, which, together with a heat evolution, will produce troostite. On quenching from higher temperatures, between Ac_1 and Ac_3, the carbon content of the martensite is lowered, the concentration gradient is less, and the troostite border is absent. When the absorption of ferrite has occurred to such an extent that the microstructure consists chiefly of dark areas of dilute martensite with ferrite boundaries, such as are obtained on quenching from 850° C., the steel is considerably toughened. In consequence, the hardness, maximum stress, &c., are decreased, while the ductility and impact values rise. At 900° C., the austenite, having absorbed all the ferrite, forms an even structure, as shown in Fig. 24, in which the carbon is uniformly distributed, although a little ferrite is still formed around the grain boundaries and in the crystallographic planes (Fig. 34). The notched-bar test gives a higher value, although the maximum stress, hardness, &c., are raised, and the ductility is lowered. Overheating to 950–1000° C. also produces low notch-toughness.

The microstructures found in the 1⅛-in. round bars were similar to those of the more rapidly cooled bars illustrated, but the steel contained larger areas of ferrite, which gave rise to increased toughness on quenching from 825–900° C. The martensitic grains formed on quenching from 730–760° C. also were more troostitic in character.

Table VIII. shows the effect of tempering mild steel after quenching from 730° C., the temperature which induces maximum embrittlement. The impact values are further decreased on heating to 100° C. This is possibly due to the change to martensite of any retained austenite, as it is claimed that even in low-carbon steels some untransformed austenite is retained on quenching.[5] The toughness increases progressively on further reheating until, at 600° C., the notched-bar value exceeds that obtained by normalising.

TABLE VIII.—*Tempering of Mild Steel Quenched from 730° C.*

Heat Treatment.	Charpy Impact Value (Average).		Hardness Number.
	Kg.m.	Ft.lb.	
As normalised . . .	17·23	125	131
W.Q. 730° C. . . .	1·16	8·4	203
W.Q. 730° C., T. 100° C. .	0·88	6·4	179
W.Q. 730° C., T. 200° C. .	3·80	27·5	162
W.Q. 730° C., T. 400° C. .	13·41	97	157
W.Q. 730° C., T. 600° C. .	19·91	144	127

The microstructure is shown in Fig. 38, and consists of finely dispersed sorbite.

Martensitic grains induce embrittlement as revealed by the notched-bar impact test, owing to the ease with which a crack is formed and propagated. The test was discussed recently at a meeting organised by the Manchester Association of Engineers on behalf of the Joint Committee on Materials and their Testing.[17] Some of the impact tests carried out with the Mesnager notch gave an absorption of energy which was not so low as that found on using the Izod notch. The embrittlement shown was also revealed in other tests, such as cold-work[11] and the bend test. It is claimed that martensitic grains in low-carbon steel formed by air-cooling have an effect on the machinability.[13]

SUMMARY.

(1) Two ingot irons and a mild steel were rapidly cooled from temperatures up to 1000° C., and their mechanical properties and microstructures were examined. The history of the materials from the ingot stage was known, and the complete chemical composition was determined.

(2) Reference is made to previous work and the lack of certain data is described. The microstructures associated with certain mechanical properties after quenching under controlled conditions from definite temperatures are correlated.

(3) There is a critical range in which marked embrittlement occurs, as shown by low notched-bar impact tests, for both ingot iron and mild steel, on rapid cooling from 875–900° C. and from 700–825° C. respectively. The embrittlement of ingot iron is reduced appreciably by a lower rate of cooling, such as the quenching of bars of increased section. Mild steel gives low impact results after quenching at both rates, but the brittle temperature range is reduced to 730–800° C. by the slower quench, while the notch toughness is regained on increasing the temperature to 825–900° C.

(4) Martensitic grains are formed in ingot iron and in mild steel by rapid cooling from approximately 830° C. and 730° C., respec-

tively. Maximum embrittlement in mild steel is due to the hard martensite formed at this temperature, which forms a network at the grain boundaries; tempering the steel at 600° C. results in a notch-toughness greater than that found in the normalised condition.

(5) Martensitic grains in ingot iron do not cause embrittlement when formed from the lower range of temperature in which γ-iron solid solution is produced, such as from 850° C. Heating to a temperature of 875° C., however, results in an appreciable increase in volume of the austenitic areas, and, on rapid cooling, dilute martensite is formed, chiefly in the neighbourhood of the grain boundaries. This gives rise to a low impact value. The martensitic areas are readily decomposed, especially on quenching from 900° C., and interfere with the character of the grain boundary material, causing marked embrittlement.

Acknowledgments are due to Messrs. Guest Keen & Baldwins, Ltd., for the facilities provided, to Professor W. R. D. Jones, D.Sc., for constant encouragement during the work, and to Professor W. Norman Thomas, M.A., D.Phil., for the unrestricted use of the Charpy impact machine.

APPENDIX.—*Aluminium-Alloy Method for the Gravimetric Determination of Total Oxygen in Plain Carbon Steels.*

BY N. GRAY, M.MET., AND M. C. SANDERS (PORT TALBOT).

Introduction.—Various methods have been devised for the determination of the total oxygen in steel, some of which, notably the vacuum fusion method, apparently give quantitative results.

Most of them, however, suffer from certain disadvantages, such as the necessity for expensive apparatus, the length of time involved, or the extreme care and skilful manipulation essential for accurate results.

In the method to be described, the principles involved are simple, the apparatus required is comparatively inexpensive, the time factor can be reduced appreciably, and an analyst, with average manipulative skill, should obtain results comparable with those given by the vacuum fusion method. The authors hope to apply the method to the routine control of the manufacture of steel.

Procedure.—The method is based on the production, under controlled conditions, of an iron-aluminium alloy which approximates to the compound $FeAl_3$. The total oxygen present in steel as FeO, Fe_2O_3, MnO, Al_2O_3, SiO_2, &c., and in various combinations, is dissociated by a large excess of aluminium at a temperature of 1100–1200° C. in an atmosphere of hydrogen with the quantitative production of alumina. It is considered that any entrapped oxygen-bearing gases are also dissociated to form alumina.

The apparatus is one which has been previously used for the "hydrogen reduction" process. It is illustrated in Fig. 39, and consists of the following parts :—

A.—A preheating furnace, at a temperature of 950° C., heating a silica tube, containing platinum gauze for the conversion to water vapour of any traces of oxygen contained in the hydrogen, which is supplied from a cylinder.

B.—A Drechsel washing bottle, containing concentrated sulphuric acid.

C.—A Nesbitt bulb, containing soda-asbestos or caustic soda.

D.—A Nesbitt bulb, containing phosphoric anhydride suspended on glass wool.

E.—A high-temperature furnace, of a split type (for rapid cooling), heated by carborundum resistance rods. This furnace is used for heating the silica tube in which the actual melting of the aluminium is carried out.

F.—A Drechsel washing bottle, containing concentrated sulphuric acid, which also acts as a seal and as a control of the rate of gas flow.

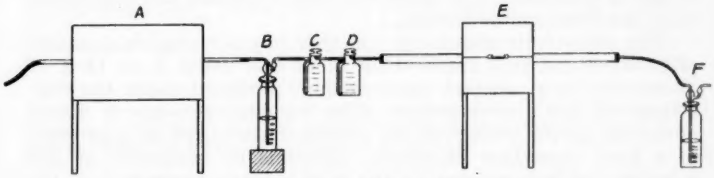

FIG. 39.—Apparatus for Oxygen Determinations.

The fusion is effected in a boat of pure electrically prepared graphite, which has been previously "blanked." Approximately 10 g. of steel, in solid form ($\frac{1}{16}$ in. maximum thickness) are carefully prepared and weighed, scale having been previously removed with emery paper and grease by suitable solvents. The specimen is sandwiched between approximately 14 g. of electrically prepared aluminium. The boat and contents are placed in the silica heating tube *E*, and all traces of oxygen are removed by passing a current of purified hydrogen in the cold for 1 hr. The furnace is then rapidly raised to 1150° C., and the temperature is maintained for an hour. The rate of flow of hydrogen is approximately 5 ml. per sec. There is no sudden or violent reaction between the aluminium and the steel, but rather a slow interaction which takes place quietly, and one hour is found to be necessary for the complete penetration of $\frac{1}{16}$ in. of steel.

At the end of this period, the current is switched off, the split furnace is opened, and the whole is allowed to cool down to room temperature, the hydrogen flow meantime being maintained. The boat is then removed, the alloy (in the solid form) and the residual alumina being placed immediately in a beaker containing 350 ml. of 1 : 1 hydrochloric acid, any slight film adhering to the boat being care-

fully removed and added to the bulk. The alloy is allowed to dissolve by its own heat of reaction. Next, 40 ml. of concentrated nitric acid are slowly added to oxidise and complete the solution of the alloy. When working on high-carbon steels, if undecomposed carbides are noticed at this stage, these are removed by the addition of the usual oxidants. A small quantity of ashless pulp is added, the mixture well stirred, and allowed to settle at a temperature of approximately 70° C. The solution is filtered through fine ashless filter paper, which is washed free from iron and aluminium salts with warm 5% hydrochloric acid and then free from acid with warm water. The precipitate is next washed with warm 3% sodium carbonate, and finally with warm 5% hydrochloric acid and warm water. It is ignited at 1000° C. in a tared platinum crucible and weighed.

The blank obtained on 14 g. of aluminium treated in the same way is deducted, and the total oxygen in the steel is calculated from the weight of alumina. The latter has been examined and was found to be free from contamination.

The electrolytic aluminium contains only a negligible quantity of alumina, and that found in the blank test (0·001 g. on 14 g. of aluminium) is a constant small amount produced under the conditions of the determination. The residual alumina is found embedded in the surface of the solidified alloy, and is apparently of a hard crystalline character. There is no indication of any solubility of the alumina in the acid solvent prescribed in the method.

TABLE IX.—*Oxygen Determinations in Steels.*

Sample No.	Description of Steel.	Vacuum Fusion Method.		"Aluminium-Alloy" Method. Average of Three Determinations.
		"Best Value."	"Acceptable Range."	
1	Low-carbon, rimming.	0·018%	0·016–0·02%	0·020%
2	Medium-carbon, high-manganese.	0·017%	0·012–0·018%	0·019%
3	Bessemer screw steel, rimming.	0·017%	0·014–0·02%	0·017%
4	Special low-carbon, aluminium-killed.	0·002%	0·001–0·004%	0·004%
5	Low-carbon, silicon-killed.	0·009%	0·007–0·011%	0·008%
6	Medium-carbon, silicon-killed.	0·007%	0·005–0·008%	0·008%
7	Open-hearth ingot iron, rimming.	0·106%	0·10–0·11%	0·105%
8	Special low-carbon, aluminium-killed.	0·017%	0·015–0·019%	0·019%

Materials Used.—The accuracy of the method was proved by determinations carried out mainly upon the eight samples of steel issued to various laboratories in 1933 by the United States National Bureau of Standards, for co-operative investigation into the various methods then being used for the determination of oxygen in steel.[18] The results obtained by the "aluminium-alloy" method are compared in Table IX. with the "best value" figure and with the "acceptable range" of figures obtained by the vacuum fusion method, from which it will be seen that close agreement is attained.

Experiments have been made on the dissociation of silica and aluminium silicate, as well as upon oxides of iron and manganese by this method. In each case the experiment was conducted as follows: A small hole was drilled in a sample of steel which had previously been tested for total oxygen, and the weight was adjusted to 10 g.

TABLE X.—*Check Tests on the Aluminium-Alloy Method.*

Compound Tested.	Weight Taken. G.	Equivalent Weight of Oxygen. G.	Total Weight of Alumina found. G.	Weight of Alumina due to Blank and the Oxygen in the Steel. G.*	Weight of Alumina Recovered. G.	Equivalent Weight of Oxygen Recovered. G.
Silica, SiO_2 . .	0·02	0·01065	0·0256	0·0027	0·0229	0·0108
			0·0253		0·0226	0·0106
Aluminium silicate, $Al_2O_3.2SiO_2$.	0·02	0·0101	0·0235	0·0027	0·0208	0·0098
			0·0234		0·0207	0·0097
Ferric oxide, Fe_2O_3.	0·04	0·012	0·0280	0·0027	0·0253	0·0119
			0·0281		0·0254	0·0119
Manganese oxide, MnO.	0·04	0·009	0·0216	0·0027	0·0189	0·0089
			0·0222		0·0195	0·0092

*The steel used in these experiments contained 0·008% of oxygen by the aluminium-alloy method. The weight of alumina formed from 10 g. of steel plus the blank from 14 g. of aluminium = 0·0027 g.

An amount of the compound approximately equivalent to 0·01 g. of oxygen was inserted in the hole, and the steel and added inclusions were submitted to the method. In each case the amount of added oxygen was recovered in the form of alumina, which was found to be free from contamination (Table X.). No oxygen escapes from the heating tube in the form of water vapour, whence it is assumed that any dissolved oxygen must also be converted into alumina. Weighing bulbs containing phosphoric anhydride were inserted many times after the heating tube, and also after a nickel catalyst tube added to the train, and in no instance was any increase in weight found. The large excess of aluminium successfully combines with all oxygen present, even in an atmosphere of hydrogen, where it might be anticipated that some oxygen would be removed in the form of water vapour.

In conclusion, the authors admit that improvements in the method are possible, chiefly in the design of the apparatus. That used was originally intended for another purpose, and they have in mind a design which will permit of a number of determinations being carried out simultaneously. The supply of a more rapid flow of purified hydrogen would probably effect a quicker evacuation of all traces of air from the heating tube, and a modification of the shape of the boat would enable a thinner section of steel to be used and thus minimise the time required for the operation. The results obtained, however, point to the complete dissociation, by an excess of

aluminium at 1150° C. in a hydrogen atmosphere, of all the oxygen-containing inclusions in plain carbon steel.

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DISCUSSION.

(Figs. C and D = Plate XXVIA.)

Mr. J. H. WHITELEY (Consett, Co. Durham) said that the authors had ably presented in this paper a straightforward piece of work which should prove of considerable value. The main item of interest was, he thought, the low Izod values given by ingot iron quenched from 870–900° C. and by mild steel quenched from 730–760° C. These results reminded him of some similar work recently published by Rolfe in a book entitled " Steels for the User." He there showed on p. 178 that a steel containing 0·07% of carbon, which was therefore intermediate between the above two materials, could give very low Izod values when quenched from 780° C., and he (Mr. Whiteley) wondered whether the cause in all three cases were one and the same. In the authors' mild steel it might, of course, have been the presence of martensite, for that constituent would undoubtedly be found to some extent in the quenched pieces. He would point out, however, that at 800° C. and above, hard martensite in much greater amounts would be retained, and yet the very low Izod values were not found. On the other hand, no martensite would remain in the ingot iron, owing to the size of the test-pieces, for it broke down with great rapidity in such material. The common factor at the different temperatures required for the three steels to produce this weakness would seem to be the volume of the austenite areas, as in all three instances it would be about the same. He would suggest, therefore, that the low Izod results were not due so much to the presence of martensite as to the relative volumes of austenite and ferrite in the steels at the quenching temperature. This supposition received a certain amount of support from the fact, stated by the authors, that the larger-sized test-pieces of mild steel gave the lowest results when quenched from 760° C., as against 730° C. for the reduced sizes. The slower speed of cooling of the larger sections would provide more time for some shrinkage of the austenite areas to occur, thus allowing the relative volumes to attain critical dimensions.

He was afraid that he could not agree with the authors' views on the formation of troostite in mild steel when quenched from just above the Ac_1 point. Carbon diffused rapidly in austenite even at that temperature, and when the areas were small a uniform solid solution was quickly formed at a stationary temperature. He had found repeatedly that when small pieces, weighing about 1 g., of mild steel with a normal manganese content were heated at 750° C. for 3–4 min. only and then drastically quenched no marginal troostite appeared. Further, in the authors' experiments, the cooling of the soaked test-pieces would be decidedly less rapid, owing to their sizes, and, consequently, the austenite areas would shrink a little, so that the carbon would tend to concentrate at the

borders. This and not the reverse was, he maintained, the condition much more likely to cause troostite to appear.

Finally, he thought the authors had made a praiseworthy attempt to solve the difficult problem of the easy estimation of the total oxygen in steel. The method they had devised certainly demanded serious attention, especially as it was so comparatively simple to work. He would ask the authors whether they were sure that the Al_2O_3 formed was totally insoluble in 50% hydrochloric acid. Unless the particles aggregated at 1150° C., which was very unlikely, many of them must be extremely small, and for that reason they might be soluble to some extent. Nevertheless, the method seemed distinctly promising. It was, in his judgment, of sufficient importance to warrant its publication as a separate paper.

Mr. T. E. ROONEY (Teddington, Middlesex) said his main object in speaking was to discuss the Appendix to the paper, and he did not know whether to congratulate the authors on inventing another chemical method for estimating oxygen. A stage had now been reached when any chemical methods proposed up to date should be subjected to a very critical examination to see what they really meant.

In Table I. the authors gave an analysis of inclusions, and he would like to ask what method they used.

Mr. SANDERS replied that the Frank Scott method was used.

Mr. ROONEY, continuing his reference to the method used for the determination described in the Appendix, said the authors cleaned their specimens with emery paper, and personally he did not like that. It was necessary to be very careful in cleaning a specimen with any abrasive for the purpose in question. They said that any slight film adhering to the boat was carefully removed and added to the bulk. As the boat was made of graphite, he wondered whether there was not some danger of scratching off some of the graphite with that slight film. It might not matter very much in the long run, however, because it would be burned off on ignition; but if there was much it would need prolonged treatment. The authors said that "When working on high-carbon steels, if undecomposed carbides are noticed at this stage, these are removed by the addition of the usual oxidants." He would like to know what was used for that purpose. They said that the residual alumina was apparently of a hard crystalline character. At a temperature of 1150° C. he rather doubted whether, if alumina were formed by the action of the other oxides, one would be left with a hard crystalline material, unless it was something in the nature of a spinel, and then, of course, it might not be pure alumina; one might have $FeO.Al_2O_3$.

The authors' results in Table IX. showed remarkable agreement

with the Bureau of Standards steels, and he was inclined to think that to some extent it was a case of a balance of errors.

On the last page of the paper, the authors said: "Weighing bulbs containing phosphoric anhydride were inserted many times after the heating tube, and also after a nickel catalyst tube added to the train, and in no instance was any increase in weight found." Personally, he was inclined to doubt that, because if graphite were heated in contact with silica at 1150° C. in an atmosphere of hydrogen, he thought that some moisture would be given off.

He would like to know whether the authors had examined their precipitates—the alumina—in order to make sure that they had got 100% alumina, because he thought that that was a very important point.

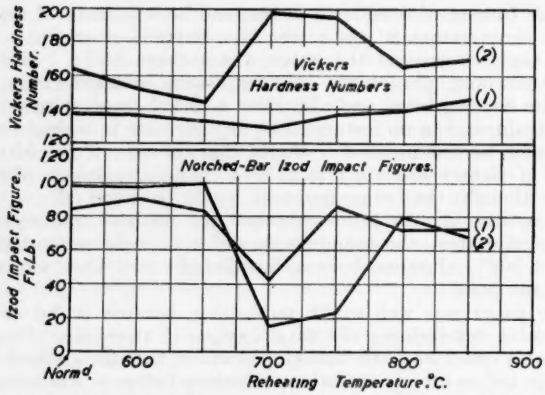
The paper was well worth publishing, because it did ease the problem of determining the total oxygen in steel in a cheap and reasonably quick way. He thought, however, that the method should be subjected to a very critical examination before it was accepted.

Mr. J. A. Jones (Stocksbridge, near Sheffield) remarked that the authors were to be congratulated on having carried through a comprehensive investigation of a type of embrittlement in ingot iron and in mild steel which had been known to occur, but with regard to which, data had been, to say the least of it, meagre. The results given in the paper were particularly complete, and the evidence collected by the authors in support of their explanation of the embrittlement was very clearly supplemented by the selection of very fine photomicrographs. He did not propose to offer any criticism of the authors' conclusions, but simply to submit, in confirmation, the results of some tests carried out on a mild steel of normal manganese content, and on one containing about $1\frac{1}{2}\%$ of manganese reheated in the range 600–850° C., but in this instance followed by air-cooling instead of water-quenching. Marked embrittlement precisely similar in character to that found by the authors in their sample of mild steel was found in the case of both of these materials.

The results, with full particulars of the steels, were shown in Fig. A.

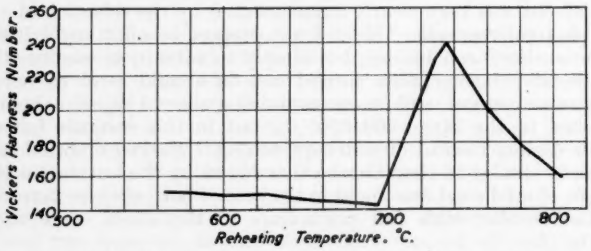
In order to obtain further data with regard to the marked hardening produced by air-cooling the $1\frac{1}{2}\%$ manganese steel from a narrow range of temperature around 750° C., a $\frac{5}{8}$-in. dia. bar was taper-heated in the range 600–800° C. and the hardness determined after air-cooling. The temperatures were determined at intervals of 1 in. along the length of the bar, by means of separate thermocouples attached to the bar. The results of hardness tests were shown in Fig. B.

Microscopical examination confirmed the results obtained by the authors and indicated that from 750° C. the formation of irresolvable martensite (with troostite) occurred at a slower rate of cooling than from 800° C. Figs. C and D illustrated the structures obtained.



(1) C, 0·15%; Mn, 0·62%; Si, 0·186%; S, 0·035%; P, 0·031%.
(2) C, 0·16%; Mn, 1·56%; Si, 0·170%; S, 0·027%; P, 0·030%.
⅝-in. dia. bars normalised from (1) 910° C., (2) 880° C., reheated for 5 hr. and air-cooled.

FIG. A.—Vickers Hardness and Notched-Bar Izod Impact Figures of Mild Steel of (1) normal manganese, (2) high manganese content, air-cooled from within the range 600–850° C.



C, 0·14%; Mn, 1·65%; Si, 0·16%; S, 0·028%; P, 0·022%.
⅝-in. dia. bars, normalised from 900° C. and then taper-heated over 4-in. length at 600–800° C. for 5 hr. and air-cooled.

FIG. B.—Vickers Hardness Numbers of Taper-Heated Bar of Mild Steel of High Manganese Content.

Dr. F. ADCOCK (Teddington) said that it was very desirable for the authors to make quite sure that the aluminium united with all the available oxygen when their specimens were dissolved in a large excess of aluminium in the presence of both hydrogen and graphite. Conceivably the hydrogen could react with some of the oxide at an early stage of the reaction.

FIG. C.—Heated for 5 hr. at 750° C., then air-cooled. × 1000.

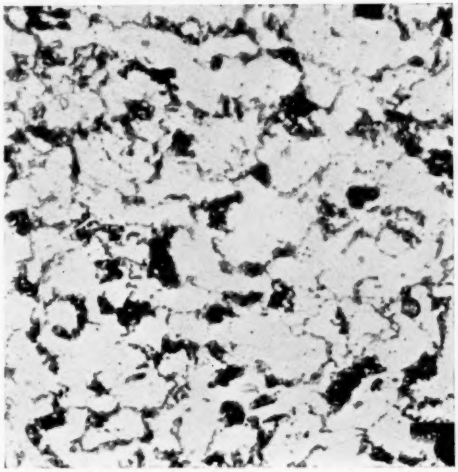


FIG. D.—Heated for 5 hr. at 800° C., then air-cooled. × 1000.

FIGS. C and D.—Mild Steel, carbon 0·14%, manganese 1·65%, air-cooled from reheating temperature. Rate of formation of irresolvable martensite (with troosite) slower from 750° C. than from 800° C.

(See J. A. Jones' contribution.)

[*Discussion on Jones & Gray.*
[*To face p.* 356 P.

FIG. E.—Martensitic Grains in a 0·07% Carbon Steel quenched from 780° C. × 1000.
(See Rolfe's contribution.)

[*Correspondence on Jones and Gray.*

[*To face p.* 357 P.

Regarding graphite or carbon, he (Dr. Adcock) had on one occasion melted an iron alloy containing about 1% of carbon in an alumina crucible under vacuum conditions. At the end of the experiment the melt had picked up 0·92% of aluminium (not alumina), while most of the carbon had passed off as carbon monoxide. The temperature was, of course, higher than that used by the authors, but the results suggested that in the authors' method the aluminium might not unite quantitatively with all the available oxygen, especially if the reaction were conducted in a graphite boat.

Had the authors examined the fractures which they obtained from the impact tests to see whether they were mainly intercrystalline, or transcrystalline in character? He hoped that the authors would not be discouraged by the many critical remarks which were bound to be elicited by a new analytical method, and he would like to congratulate them on both the main paper and the Appendix.

CORRESPONDENCE.

(Fig. E = Plate XXVIB.)

Mr. R. T. Rolfe (Bedford) wrote that this paper represented a research of the greatest value, which filled a considerable gap in our fundamental knowledge concerning heat-treatment problems.

The results afforded much additional information applicable in case-hardening practice, particularly as to the effect, on the core of the article, of various heat treatments commonly used in industrial practice. The writer had already put on record [1] the results of a large number of duplicate tests showing the varying mechanical quality of the core obtained by different treatments of a steel containing 0·07% of carbon, when the marked embrittlement caused by the production of martensitic grains at the ferrite grain boundaries was particularly evident after certain treatments.

Thus an average Izod value of over 120 ft.lb. in the normalised state was reduced to an average value of only 4 ft.lb. after soaking for 12 hr. at 900° C. for carburising, and cooling in the box, followed by reheating to 780° C. and quenching. Here the low reheating temperature had permitted only a very little diffusion of carbon from the original pearlite areas into the surrounding ferrite, so that, on quenching, the whole of the inner portions of each of the original pearlite grains were martensitic, as shown, at a magnification of 1000 diameters, in Fig. E, which was the writer's original Fig. 59 *b*, now at higher magnification. Reheating to 900° C., followed by quenching, resulted in an average Izod value of 60 ft.lb., where the higher reheating temperature, and the correspondingly greater diffusion, into the ferrite, of the carbon of the original pearlite, prevented the local production of the high-carbon martensite,

[1] "Steels for the User," pp. 178–179. London, 1937: Chapman & Hall Ltd.

previously noted. This explanation agreed well with that advanced by the authors on p. 345 of their paper, lines 22–33, and their conclusions Nos. (4) and (5). Linking up with his own work, the writer would be inclined to amplify the beginning of conclusion No. (4) on p. 347 as follows : "Martensitic grains are formed in ingot iron (carbon 0·020%), 0·07% carbon steel and 0·15% carbon steel, by rapid cooling from temperatures of 830°, 780° and 730° C., respectively."

In conclusion, the writer congratulated the authors on a highly important contribution to the study of carbon steels, which he had recently described as a much neglected field (*loc. cit.*, preface) and where he had strongly suggested (*loc. cit.*, p. 183) that, "even at the present time, case-hardening phenomena could be studied more intensively with advantage.". He had scarcely expected, however, so speedy a rectification of one of the many omissions in our desirable knowledge.

AUTHORS' REPLY.

The AUTHORS, in reply, wished to thank those who had contributed to the discussion. Mr. Whiteley had referred to the very low impact values found on quenching ingot iron from 875–900° C., 0·15% carbon steel from 730° C. and 0·07% carbon steel from 780° C.; the authors said that, broadly speaking, the same cause was at work. They had carried out tests on mild steels containing less carbon than 0·15%, and they found that it was necessary to increase the quenching temperature to above 730° C. to induce maximum embrittlement. They would agree that the embrittlement described was not caused by the mere presence of martensitic grains in low-carbon steels, although this happened to be the case in their 0·15% carbon steel. It was necessary that a critical *volume* of austenite be formed in the ferrite structure, and this, on quenching, controlled the amount of martensite produced. This critical amount of martensite influenced the grain boundaries of the ferrite. On quenching the 0·15% carbon steel from a temperature immediately above Ac_1, martensitic grains were formed as a continuous layer around the ferrite grain boundaries, and these could be looked upon as extremely hard inclusions which facilitated the formation and propagation of a crack, thus giving low notched-bar impact values. Heating the steel to temperatures above 800° C. and quenching did not cause such marked embrittlement, owing to the fact that the volume of martensite, being greater, lessened the grain-boundary disturbance, whilst also its carbon content and hardness value were not so great. It appeared that in 0·07% carbon steel sufficient martensite was produced on quenching from 780° C. to cause embrittlement. In ingot iron containing 0·02% of carbon, although austenite was formed at 830° C., it was necessary to heat the metal to temperatures within the upper

part of its critical range (875–900° C.) in order to produce the necessary *volume* of austenite, which, on quenching, dissociated in the neighbourhood of the grain boundaries and thus caused embrittlement. Martensitic grains found in ingot iron on quenching from 830–850° C. did not cause embrittlement, because the volume was insufficient to influence the character of the grain boundaries.

Mr. Whiteley did not agree with them as to the cause of the formation of troostite. There were, as a matter of fact, various views on its formation. The authors found that the troostitic border of martensite was reduced to a minimum by increasing the rate of cooling, such as by the quenching of very small specimens. A slow rate of cooling—by quenching the larger test bars—on the other hand, produced structures composed of ferrite and troostite with practically no martensite. This structure was also associated with embrittlement.

They thanked Mr. J. A. Jones for his complimentary remarks, which they greatly appreciated, and also for illustrating the embrittlement which occurred in mild steel containing a high manganese content on air-cooling. It was extremely interesting to find that air-cooling from temperatures within the critical range, and particularly from those temperatures just above Ac_1, produced such low notched-bar impact values, which were evidently caused by the presence of martensitic grains similar to those found by the authors.

In reply to Dr. Adcock, the authors had not carried out microscopical tests to find the path of the impact test fractures. The brittle impact test-pieces from both ingot and mild steel showed a coarse glaring type of fracture, which was quite different in character from the others.

The authors thanked Mr. Rolfe for his interesting written discussion and for his kind appreciation of the paper. They had already referred to the 0·07% carbon steel mentioned by Mr. Whiteley. Mr. Rolfe did not carry out the quenching test on the normalised steel, but after soaking it for 12 hr. at 900° C. and then cooling it slowly in the box within the furnace. This annealing treatment itself would reduce the impact value of the steel to a figure appreciably less than that obtained by normalising, and the impact values were further reduced to only 4 ft.lb. after reheating to 780° C. and quenching. The embrittlement was associated with martensitic grains at the grain boundaries, as illustrated by Mr. Rolfe in his excellent photomicrograph to which he referred. The authors did not agree with him in his amplification of their summary that "martensitic grains are formed in ingot iron, 0·07% carbon steel, and 0·15% carbon steel by rapid cooling from temperatures of 830°, 780°, and 730° C., respectively." The temperatures stated by the authors denoted the first appearance of martensite on quenching, whereas in a pearlitic steel containing 0·07% of carbon the presence of martensitic grains should be observed on quenching from temperatures nearer the Ac_1 temperature than 780° C., although

the maximum embrittlement of the steel would not occur until a critical volume of martensite was formed, such as by quenching from 780° C.

With reference to the method for the determination of oxygen, the authors stated, in reply to Mr. Whiteley, that the alumina formed was definitely insoluble in hydrochloric acid. It generally appeared to be of a crystalline character, but it had not been examined microscopically. Its state of division seemed to vary with the compound from which it was formed. In other words, the type of alumina obtained from the dissociation of FeO would be rather different in appearance from that obtained from SiO_2 or MnO. Generally, however, it appeared to be crystalline.

In reply to Mr. Rooney, they said that the method used for the determination of the inclusions was an electrolytic one, published by Frank Scott. It was based on the electrolysis of steel in a solution of iodine in magnesium iodide. The authors had had much experience of this method and were satisfied that, as far as silica, alumina and MnO were concerned, very good figures were obtained. With regard to FeO, however, they felt some reserve as to whether it did not give slightly high results. The samples for oxygen determination had been cleaned with emery, but latterly, to obviate any possible inclusion of the abrasive powder, the cleaning had been carried out with a smooth file. The removal of the film on the boat was effected very carefully, and this film was very slight. The graphite used was very pure, and if any scrapings were obtained from the boat they would be small and oxidised during ignition without leaving any residue, thus having no influence on the result. Ammonium persulphate was the oxidant used when required. They had not been able to find any increase of weight due to moisture by the introduction of a P_2O_5 tube. They had done a great deal of work on the apparatus in connection with the hydrogen reduction method for the determination of oxygen, and had been able to reduce the blank obtained to a very low figure. They thought that the absence of any increase in weight in the moisture tube indicated the ability of the molten aluminium to dissociate any traces of moisture formed before it left the furnace. With regard to the possible formation of a spinel, the residue of alumina had been examined frequently for impurities with negative results, and, in addition, various oxides, such as those given in Table X., had been dissociated completely with the quantitative recovery of the oxygen content as Al_2O_3.

Dr. Adcock asked whether the authors were certain that the aluminium united with all the available oxygen, and he suggested that some might pass off with the hydrogen. In the paper the authors had given proof that no oxygen escaped in the form of moisture, as stated above. The steel was soon surrounded by a covering of molten aluminium, so that by the time the hydrogen might possibly react with the oxides in the steel, the latter was already amply protected.

THE EFFECT OF CHROMIUM AND CARBON CONTENTS ON THE COEFFICIENTS OF THERMAL EXPANSION OF CHROMIUM STEELS.[1]

By J. A. JONES, M.Sc., F.Inst.P., and W. C. HESELWOOD, B.Sc., A.Met.
(Stocksbridge, near Sheffield).

(Fig. 4 = Plate XXVII.)

Synopsis.

The construction of a sensitive dilatometer for the accurate determination of coefficients of thermal expansion up to 1000° C. is described, and results are presented of measurements of the coefficients of expansion of two series of chromium steels, (*a*) low-carbon steels containing up to 32% of chromium, and (*b*) medium-carbon steels containing up to 19% of chromium.

With increasing chromium content, the low-carbon series shows a continuous decrease in the expansion coefficients. In medium-carbon steels, however, the effect of chromium additions up to approximately 4½ times the carbon content is to increase the values of the expansion coefficients, especially at the lower temperatures; further additions of chromium have the effect of lowering the values, the general form of the curves becoming similar to those obtained for the lower-carbon steels. This phenomenon appears to be associated with the ratio of the chromium to the iron in the carbides present in the steels.

Introduction.

In view of the increasing demand for steels with specified values for the mean coefficient of expansion over a given range of temperature, a systematic study of the effect of various alloy elements on the values of the coefficient of thermal expansion of steel has been proceeding for some time in the Central Research Department of The United Steel Companies, Ltd.

Chromium steels were dealt with first, as alloys with a wide range of chromium content are now used commercially, many of them in high-temperature services.

The results of previous investigations summarised by Greaves [2] indicate that an increasing chromium content progressively reduces the coefficient of expansion, whilst variations of the carbon content normally met with in chromium steels have only a small effect.

[1] A communication from the Central Research Department, The United Steel Companies, Limited, Stocksbridge, near Sheffield, received January 5, 1938.

[2] R. H. Greaves, "Chromium Steels," p. 228. London, 1935: H.M. Stationery Office.

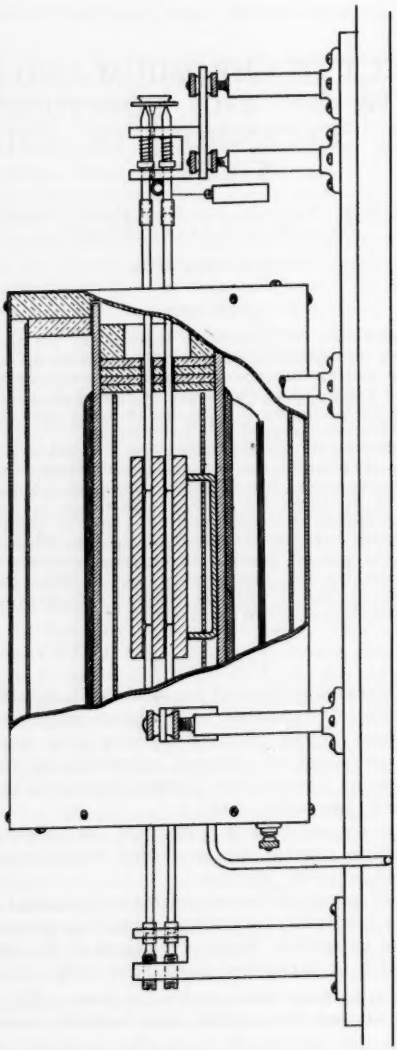


FIG. 1A (*see* Fig. 1B).—The Construction of the Dilatometer.

In view of the absence, in many instances, of exact details of the composition or treatment of the steels and of the accuracy of the determinations, it was decided to redetermine the data on a series of steels made under the same conditions and containing the minor elements in amounts similar to the minimum contents normally found in commercial steels.

The tests were carried out in a specially constructed dilatometer.

Description of the Dilatometer.

Diagrammatic sections of the apparatus are shown in Fig. 1, whilst Fig. 4 is a photograph of the general assembly.

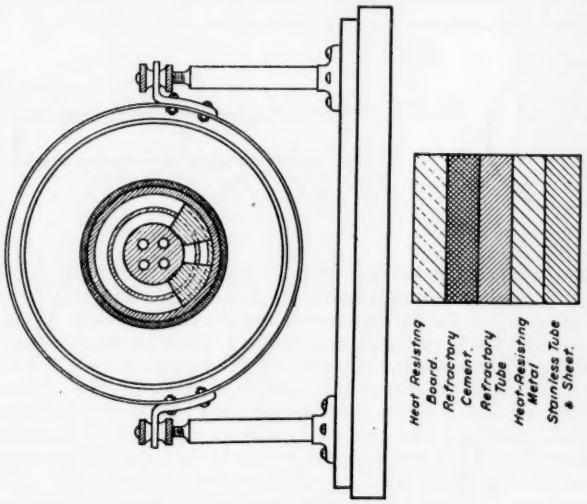


FIG. 1B (*see* Fig. 1A).—The Construction of the Dilatometer.

In principle, the differential expansion between the metal specimen and similar specimens of fused silica is arranged to rotate a mirror by means of suitable extension rods. The rotation of this mirror is observed by the usual telescope-and-scale arrangement.

Particular attention has been paid in the design of the furnace to ensure (1) that the temperature is uniform along the whole length of the test-piece, and (2) that the specimen, the silica reference rods and the thermocouple are all at the same temperature.

In the centre of the furnace is a heat-resisting steel block, 6 in. $\times$ $1\frac{3}{4}$ in. in dia. Parallel to the axis of the block are four holes each $\frac{9}{32}$ in. in dia., symmetrically situated at the corners of a $\frac{5}{8}$-in. square. The metal specimen is 4 in. $\times$ $\frac{1}{4}$ in. in dia. and rests

in the block in position *A*, Fig. 2; in positions *B* and *C* rest similar specimens of fused silica, whilst temperature measurements are taken by a thermocouple in position *D*.

The furnace winding is 10 in. in length and is wound on a refractory tube 3½ in. in dia. Between, and concentric with the heater and the block, is a heat-resisting metal tube, 10 in. × 2½ in. in dia. The heat from the winding has, therefore, to pass through the refractory tube, across an air-gap, through the metal tube and across a second air-gap to the block containing the rods. The outside of the furnace is well lagged with insulation powder, the outside case being double and consisting of two highly polished stainless-steel cylinders.

During a test, a slow stream of dried nitrogen is passed through the furnace to minimise the oxidation of the specimen.

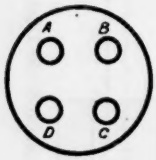


FIG. 2.

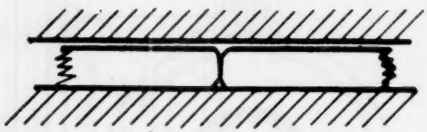


FIG. 3.

Fused-silica extension rods project out of both ends of the furnace from the specimens in positions *A*, *B* and *C*. The ends of the specimens and of the extension rods are shaped as shown in Fig. 3, the object of the bevel being to provide a space for any extraneous particles rather than allow them to settle between the contact faces during assembly or during the test. On one side the extension rods connect to fine screw adjusters, and on the other side to three steel rods hardened and ground to a good sliding fit in a suitable metal head, each rod being lightly spring-loaded to maintain contact between the specimen and the extension rods. The outer ends of the steel rods are ground to a point and make contact with a hardened steel plate, the rod in position *B* engaging in a small conical hole, that in position *C* engaging in a groove in line with the centre of the indent, whilst the rod in position *A* touches upon the surface. The hardened plate, upon which a plane mirror is mounted, is kept in contact with the points by a weight connected to a light cord that passes over a small pulley and is attached to the centre of the plate.

With the metal and silica specimens in the positions stated, the differential expansion is confined to the horizontal plane, and the rotation of the mirror is measured by a telescope and illuminated scale set up about 11 ft. away from the mirror.

The total arrangement gives a magnification of 414, and since it is possible to estimate scale readings to 0·1 mm., length changes of the order of 1/4,000 mm., or 0·00001 in., can be observed and

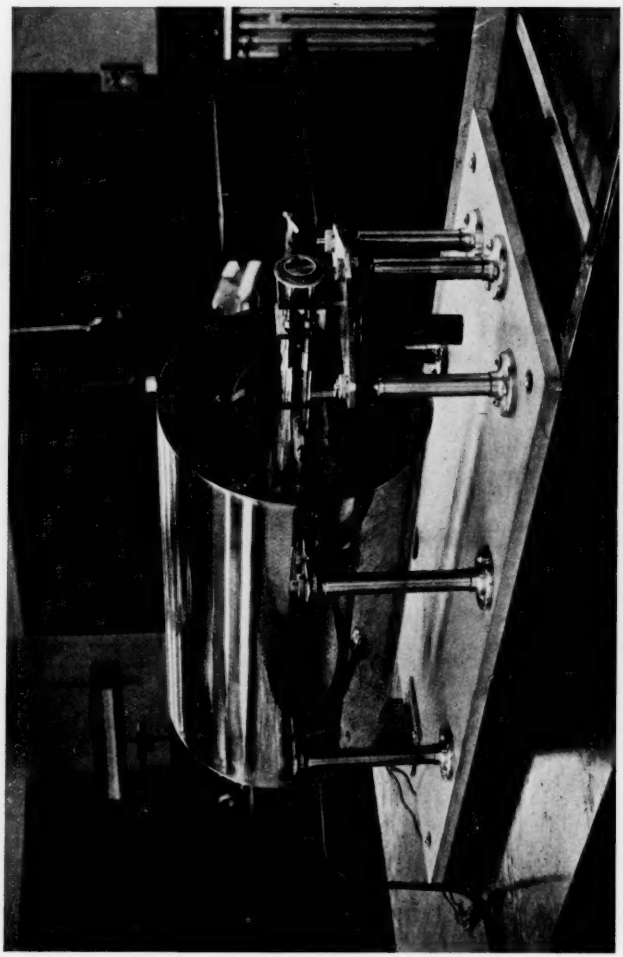


FIG. 4.—General Assembly of the Dilatometer.

[*Jones and Heselwood.*

[*To face p.* 364 P.

UNIV. OF MICH.

measured. This sensitivity on a 4-in. test-piece is more than sufficient for all ordinary purposes. The coefficients of thermal expansion are checked to $0{\cdot}05 \times 10^{-6}$ per °C., and are here reported to this value, corresponding to an accuracy of 0·5% or better.

Particulars of the Steels.

Two series of steels were made in a 35-kVA. high-frequency furnace of 18 lb. capacity, of the Ajax-Northrup spark-gap type. The first series contained 0·10% of carbon with chromium contents of up to 32%, and the second series 0·35% of carbon with chromium contents of up to 19%. The ingots were forged to ½-in. dia. bar. The bars were heated to 940° C., and very slowly cooled in the furnace before being machined to test specimens.

The analyses of the bars are given in Tables I. and II. The sulphur and phosphorus contents of the steels were of the order of 0·02%.

TABLE I.—*Analyses of the Low-Carbon Chromium Steels.*

Steel No.	1.	2.	3.	4.	5.	6.	7.	8.	9.
Carbon. %	0·09	0·10	0·11	0·11	0·11	0·12	0·12	0·13	0·12
Manganese. %	0·26	0·31	0·28	0·27	0·26	0·25	0·28	0·36	0·36
Silicon. %	0·18	0·18	0·18	0·18	0·19	0·19	0·21	0·22	0·26
Chromium. %	Nil	1·38	2·90	4·76	8·12	11·96	17·48	24·53	32·27

TABLE II.—*Analyses of the Medium-Carbon Chromium Steels.*

Steel No.	10.	11.	12.	13.	14.	15.
Carbon. %	0·36	0·35	0·37	0·37	0·38	0·43
Manganese. %	0·32	0·31	0·33	0·31	0·34	0·35
Silicon. %	0·20	0·19	0·21	0·14	0·22	0·28
Chromium. %	Nil	0·75	1·57	2·68	7·67	18·88

Preliminary Tests.

The results of preliminary tests indicated that the steels when annealed (slowly cooled from 940° C.) were not in a stable condition, as successive tests taken up to a temperature of 700° C. were found to give different values for the coefficient of expansion. After each retest the specimens were cooled very slowly in the dilatometer, a period of 16 hr. being required to cool to 40° C. Final figures were only considered satisfactory when consecutive tests gave values agreeing to within $0{\cdot}05 \times 10^{-6}$ per °C.

There was a trend during repeated reheatings towards lower values of expansion coefficients in all the low-carbon chromium

steels, especially in those containing 8·12, 11·96 and 17·48% of chromium.

Table III. gives the results of successive determinations carried out on the steel containing 11·96% of chromium.

TABLE III.—*Results of Successive Determinations of Coefficient of Expansion on Steel* 6.

Carbon 0·12%, chromium 11·96%.

Test. No.	Mean Coefficients of Expansion × 10^6.					
	20–200° C.	20–300° C.	20–400° C.	20–500° C.	20–600° C.	20–700° C.
1	$11{\cdot}5_0$	...	$12{\cdot}1_5$	$12{\cdot}4_5$	$12{\cdot}7_0$	$12{\cdot}9_5$
2	$11{\cdot}3_5$	...	$11{\cdot}9_0$	...	...	...
3	$11{\cdot}2_5$	...	$11{\cdot}8_0$	...	$12{\cdot}5_0$	$12{\cdot}7_5$
4	$11{\cdot}2_0$	$11{\cdot}5_0$	$11{\cdot}7_5$	$12{\cdot}1_0$	...	...
5	$11{\cdot}2_0$	$11{\cdot}5_0$	$11{\cdot}7_0$	$12{\cdot}0_0$	$12{\cdot}3_5$	$12{\cdot}6_0$
6	$11{\cdot}1_5$	$11{\cdot}4_5$	$11{\cdot}7_0$	$12{\cdot}0_0$	$12{\cdot}3_0$	$12{\cdot}5_5$

Similar effects were also noted in the medium-carbon steels.

It would appear that the steels in the initial annealed condition were not in true equilibrium, with the result that the chromium present was not exerting its full influence. As a result of the successive slow coolings from 700° C. the steels were brought into a more stable condition, and the full effect of the chromium present becomes evident in the lowering of the values for the coefficient of expansion.

Mean Coefficients of Thermal Expansion of the Steels.

Determinations of the mean coefficients of thermal expansion were carried out over temperature ranges up to 700° C. and the results are given in Tables IV. and V.

TABLE IV.—*Mean Coefficients of Thermal Expansion for the Series of Low-Carbon Chromium Steels.*

	Mean Coefficients of Expansion × 10^6.								
Steel No.	1	2	3	4	5	6	7	8	9
Chromium. %	Nil	1·38	2·90	4·76	8·12	11·96	17·48	24·53	32·27
20–200° C.	$12{\cdot}9_5$	$12{\cdot}6_0$	$12{\cdot}4_0$	$12{\cdot}0_5$	$11{\cdot}5_0$	$11{\cdot}1_5$	$10{\cdot}7_0$	$10{\cdot}4_0$	$10{\cdot}2_0$
20–300° C.	$13{\cdot}6_5$	$13{\cdot}1_5$	$12{\cdot}9_0$	$12{\cdot}5_0$	$11{\cdot}9_0$	$11{\cdot}4_5$	$11{\cdot}0_0$	$10{\cdot}7_0$	$10{\cdot}5_0$
20–400° C.	$14{\cdot}1_5$	$13{\cdot}6_0$	$13{\cdot}3_5$	$12{\cdot}9_0$	$12{\cdot}3_0$	$11{\cdot}7_0$	$11{\cdot}3_0$	$11{\cdot}0_0$	$10{\cdot}8_0$
20–500° C.	$14{\cdot}5_0$	$14{\cdot}0_0$	$13{\cdot}7_5$	$13{\cdot}3_0$	$12{\cdot}6_0$	$12{\cdot}0_0$	$11{\cdot}5_5$	$11{\cdot}3_0$	$11{\cdot}0_0$
20–600° C.	$14{\cdot}8_0$	$14{\cdot}4_0$	$14{\cdot}1_0$	$13{\cdot}6_0$	$12{\cdot}9_0$	$12{\cdot}3_0$	$11{\cdot}8_0$	$11{\cdot}5_0$	$11{\cdot}1_0$
20–700° C.	$15{\cdot}2_0$	$14{\cdot}7_5$	$14{\cdot}4_0$	$13{\cdot}9_5$	$13{\cdot}1_5$	$12{\cdot}5_0$	$12{\cdot}0_5$	$11{\cdot}7_0$	$11{\cdot}4_0$

TABLE V.—*Mean Coefficients of Thermal Expansion for the Series of Medium-Carbon Chromium Steels.*

	Mean Coefficients of Expansion × 10^6.					
Steel No. . .	10	11	12	13	14	15
Chromium. %. .	Nil.	0·75	1·57	2·68	7·67	18·88
20–200° C. .	$12{\cdot}5_5$	$12{\cdot}6_5$	$12{\cdot}8_5$	$12{\cdot}4_5$	$11{\cdot}6_5$	$10{\cdot}6_5$
20–300° C. .	$13{\cdot}3_0$	$13{\cdot}3_5$	$13{\cdot}4_0$	$12{\cdot}9_5$	$12{\cdot}1_5$	$11{\cdot}0_0$
20–400° C. .	$13{\cdot}8_5$	$13{\cdot}9_0$	$13{\cdot}8_0$	$13{\cdot}4_5$	$12{\cdot}5_5$	$11{\cdot}3_0$
20–500° C. .	$14{\cdot}3_0$	$14{\cdot}3_0$	$14{\cdot}1_5$	$13{\cdot}8_0$	$12{\cdot}9_0$	$11{\cdot}6_0$
20–600° C. .	$14{\cdot}7_5$	$14{\cdot}6_5$	$14{\cdot}4_5$	$14{\cdot}1_5$	$13{\cdot}1_5$	$11{\cdot}8_5$
20–700° C. .	$15{\cdot}2_0$	$15{\cdot}0_0$	$14{\cdot}6_5$	$14{\cdot}4_5$	$13{\cdot}3_5$	$12{\cdot}1_0$

Discussion of the Results.

Fig. 5 shows the effect of additions of chromium in lowering the coefficient of thermal expansion of low-carbon steel.

In Fig. 6 the results have been plotted for the individual steels of the low-carbon series. The inflection at a temperature of about 600° C. in the curve for the steel containing approximately 32% of chromium was quite definite and reversible on cooling from 700° C.

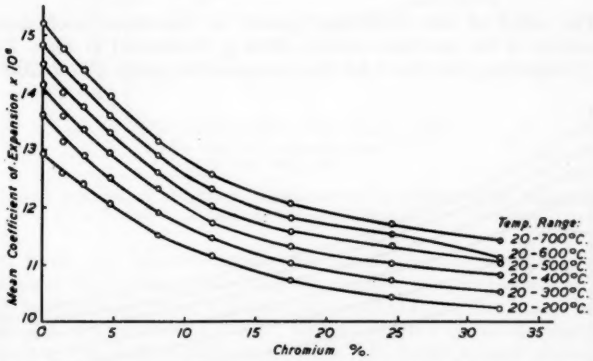


FIG. 5.—Effect of Chromium on the Mean Coefficient of Expansion of Steels containing 0·10–0·12% of Carbon.

A similar effect in chromium-iron alloys was observed by Chevenard,[1] who associated the phenomenon with the A_2 (Curie) point. It is not clear that this is a complete explanation, since the curve for steel No. 8, in which the A_2 point occurs at 635° C., showed no

[1] P. Chevenard, "Les Alliages de Fer, de Nickel et de Chrome," *Travaux et Mémoires du Bureau International des Poids et Mesures*, 1927, vol. 17.

similar inflection in repeated dilatation tests over a range of temperature up to 700° C. The full explanation of the behaviour of steel No. 9 must await further investigation.

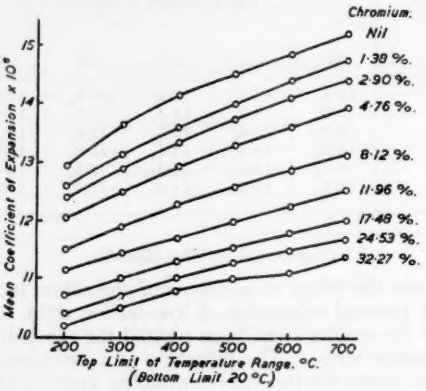


FIG. 6.—Variation of the Mean Coefficient of Expansion with Temperature for a Series of Chromium Steels (0·10–0·12% of Carbon).

The effect of the chromium content on the mean coefficient of expansion of the medium-carbon steels is illustrated in Figs. 7 and 8. Considering the curve for the temperature range 20° to 200° C.,

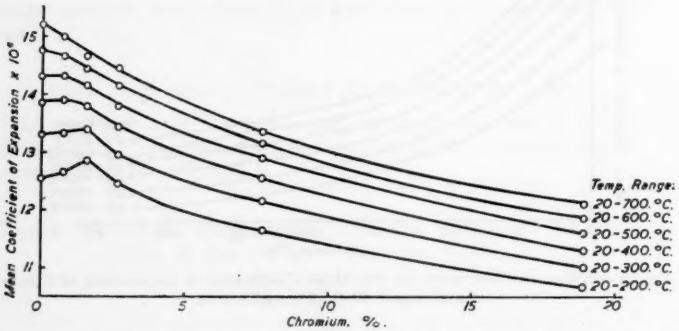


FIG. 7.—Effect of Chromium on the Mean Coefficient of Expansion of Steels containing 0·35–0·40% of Carbon.

it will be seen that an addition of chromium up to approximately 1·5% increases the value of the coefficient of expansion, but further additions have the effect of lowering the value, the general form of

the curve becoming similar to that obtained with the lower-carbon steels. The average carbon content of the first four steels in the series of medium-carbon steels may be taken as 0·36%. The chromium content at which the maximum value is obtained cannot be stated accurately, but obviously approximates to 1·5%. The ratio of the chromium to the carbon content in the steel giving the inflection on the curve is thus approximately $1{\cdot}5/0{\cdot}36 = 4{\cdot}2$.

Edwards and Norbury [1] found from the results of resistivity measurements on chromium steels that only the chromium in excess of 4·3 times the carbon content had any appreciable influence on the resistivity, and suggested that the first effect of the chromium

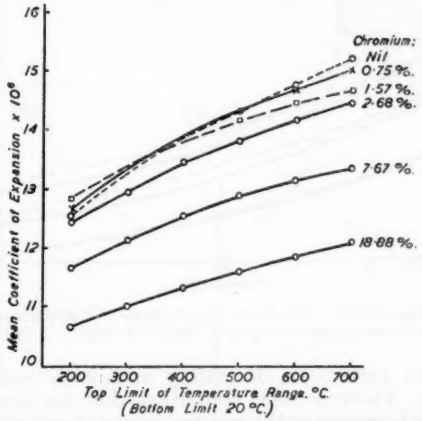


FIG. 8.—Variation of the Mean Coefficient of Expansion with Temperature for a Series of Chromium Steels (0·35–0·40% of Carbon).

is to form the double carbide $Fe_3C.Cr_3C_2$ ($Cr : C = 4{\cdot}3 : 1$), after which the chromium exerts its normal effect on the resistivity.

It is significant that a similar ratio holds for a maximum in the coefficient-of-expansion curves. Opinions differ as to the carbides present in low-carbon chromium steels. It would appear probable [2] that the carbides present in these steels are Fe_3C and Cr_3C_2 existing as a mixture, not as a compound, the chromium carbide gradually replacing the iron carbide as the chromium content is increased.

The curves of coefficient of expansion for the medium-carbon steels indicate some change in the condition of the chromium after the mixture of $Fe_3C + Cr_3C_2$ reaches equimolecular proportions.

[1] C. A. Edwards and A. L. Norbury, *Journal of the Iron and Steel Institute*, 1920, No. I., p. 447.

[2] R. H. Greaves, *loc. cit.*, chapter IV.

Maurer [1] found that, whereas additions of chromium to iron caused a fall in the coefficient-of-expansion values, additions of Cr_3C_2 first caused an increase, with a maximum at about 2% of Cr_3C_2 (*i.e.*, 1·75% of chromium and 0·25% of carbon).

It is possible that with increasing chromium additions no further Cr_3C_2 is formed (the first action of which appears to be to increase the coefficient of expansion), but that the residual chromium enters mainly into solution in the iron and results in a lowering of the values of the coefficient, the form of the curve then becoming similar to but displaced slightly above the curve for the series of lower-carbon steels (Fig. 9).

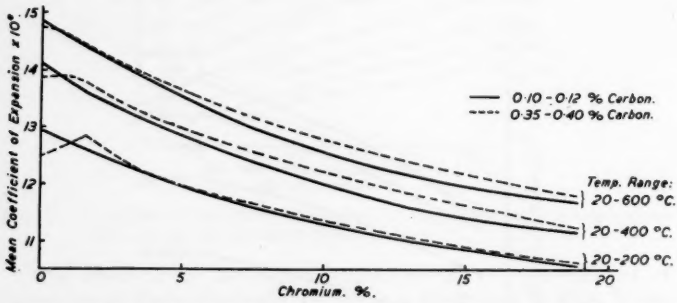


FIG. 9.—A Comparison of the Mean Coefficients of Expansion of Chromium Steels containing 0·10–0·12% and 0·35–0·40% of Carbon.

The effect persists in decreasing magnitude with increasing temperature. There is some indication that for increasing temperatures the inflection in the curves occurs at lower chromium contents, possibly owing to a decrease in the chromium-to-iron ratio in the carbides with increasing temperature.

With regard to the series of low-carbon steels, if a sufficient number of steels were examined with chromium contents below 1%, an inflection would probably be found in the curves at approximately 0·45% of chromium, but the effect would be appreciably smaller than that found in the higher-carbon steels.

In conclusion, the authors wish to express their thanks to Dr. T. Swinden, Director of Research, The United Steel Companies, Ltd., for permission to publish this paper.

[1] E. Maurer and W. Schmidt, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1921, vol. 2, p. 5.

CORRESPONDENCE.

Professor BASIL NICHOLAS SVETCHNIKOFF (Dnepropetrovsk, U.S.S.R.) wrote that in the authors' interesting work the anomaly on the curves showing the relationship between the coefficient of thermal expansion and the composition of the alloy corresponding to the minimum on the γ-loop was not referred to. In Fig. A were shown the curve of the Ac_3 points constructed according to the experimental results of Adcock [1] (continuous line), the density curve

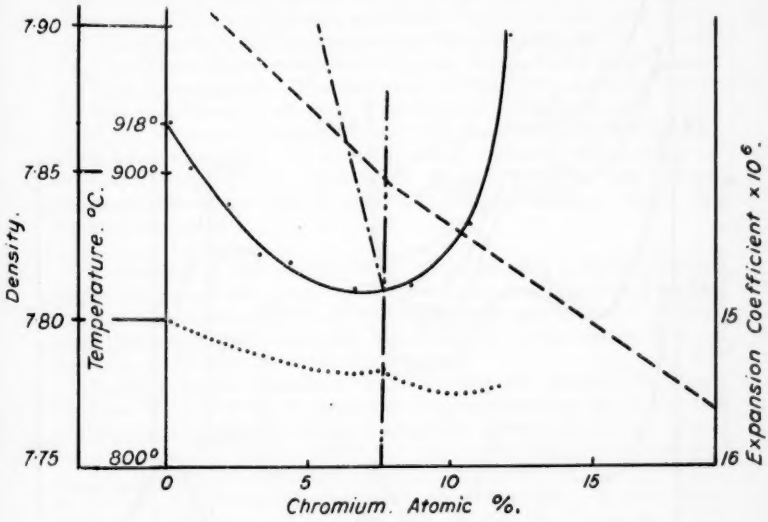


FIG. A.

computed by the writer according to the parameters established by Preston [2] (broken line), and the curve of average expansion coefficients (for a range up to 800° C.) (dotted line) constructed on the basis of Austin and Pierce's data.[3]

Attention was attracted by the coincidence of the minimum on the curve of the Ac_3 points with the break on the density curve, and the maximum on the curve of coefficients of thermal expansion corresponding to 7·6 atomic-% of chromium ($Fe_{12}Cr$). At about the

[1] F. Adcock, *Journal of the Iron and Steel Institute*, 1931, No. II., pp. 99.
[2] G. D. Preston, *Journal of the Iron and Steel Institute*, 1931, No. II., p. 139.
[3] J. B. Austin and R. H. H. Pierce, jun., *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1935, *Iron and Steel Division*, vol. 116, p. 289.

same chromium content, on the curves illustrating the relationship between the magnetic flux and the chromium content constructed by Webb,[1] a definite minimum would be seen, which was very pronounced at H = 0·5, but not at all noticeable at H = 5 and higher. This anomaly was still more distinctly demonstrated by the isotherms

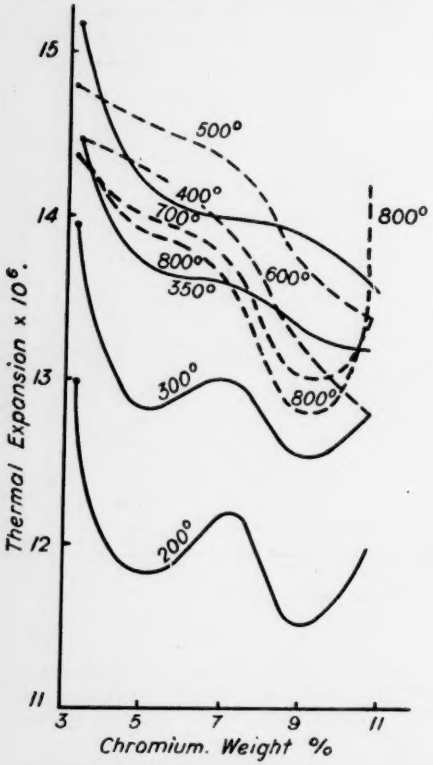


FIG. B.

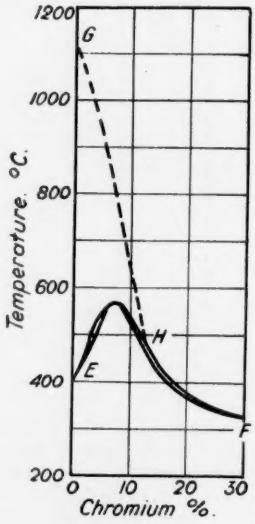


FIG. C.

of the true coefficients of thermal expansion drawn by the writer on the basis of the data of Austin and Pierce and shown in Fig. B. From these isotherms it appeared as if at 7·6 atomic-% of chromium the formation of a superstructure occurred in the alloy. On the curve for 200° C. two branches, convex to the concentration axis, inter-

[1] C. E. Webb, *Journal of the Iron and Steel Institute*, 1931, No. II., p. 141.

sected at a clearly visible maximum corresponding to a concentration of 7·6 atomic-% of chromium. As the temperature rose this maximum gradually decreased; above 300° C. it was somewhat displaced towards higher chromium contents and was perfectly smoothed out between 400° and 500° C. At temperatures above 500° C. the isotherms were lowered, and a tendency to the formation of a pronounced maximum, possibly corresponding to the composition Fe_3Cr, was observed. The connection between this anomaly and the minimum on the γ-loop was quite obvious. It was interesting to note that on the curve of the $\alpha \longrightarrow \beta$ transformation in the cobalt-chromium alloys a maximum appeared (Fig. C, according to Wever and Haschimoto [1]) at the composition corresponding to the formula $Co_{12}Cr$. These phenomena were of great interest and had hitherto not been investigated. The minimum on the γ-loop occurred also in the iron-molybdenum alloys. It was a pity that this range of alloys (5–9% of chromium) were not dealt with in Adcock's investigations when he was studying the iron-chromium alloys by the method of electrical conductivity. This might be attributed to the narrow concentration range and to the low temperatures at which the anomaly occurred.

Professor P. CHEVENARD (Paris) wrote to offer a few comments on the subject of the paper by Messrs. Jones and Heselwood on the thermal expansion of alloys of iron, chromium and carbon. He had read this paper with attention and had been surprised to find no reference to his own work on this subject.

In effect, he had published [2] in 1927 a diagram covering the range between 0% and 42% of chromium and representing the isotherms of the true coefficient of thermal expansion of iron-chromium alloys between $-100°$ and $+1000°$ C. This diagram, reproduced in Fig. D, showed clearly the progressive diminution of the expansion of iron with increasing quantities of chromium. The authors referred to this paper only in order to discuss the existence of an anomaly in the true coefficient of expansion which accompanied the magnetic transformation of iron-chromium alloys.

The authors had thought it necessary to repeat the earlier work on the expansion of chromium steels because, they said, they had observed the absence in many cases of exact details of the composition, the treatment of the steels and the accuracy of the determinations. He, Professor Chevenard, felt that this reproach could not be levelled against his own paper. In fact, the analysis of the alloys studied, their mode of preparation and the origin of the raw materials were clearly indicated; the alloys were studied in the annealed

[1] F. Wever and U. Haschimoto, *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1929, vol. 11, p. 293.

[2] P. Chevenard, "Experimental Researches on the Alloys of Iron, Nickel and Chromium," *Travaux et Mémoires du Bureau International des Poids et Mesures*, 1927, vol. 17.

condition, some after forging, others after casting, these various treatments being clearly indicated. Finally, the accuracy of the results was discussed at length.

He (Professor Chevenard) proposed to return to this question of accuracy and in particular to compare his own results with those of the authors. Secondly, with the aid of unpublished experimental work, he would show the undoubted existence of an anomaly in the expansion of iron-chromium alloys, corresponding with the magnetic transformation and in the neighbourhood of the Curie point. Finally,

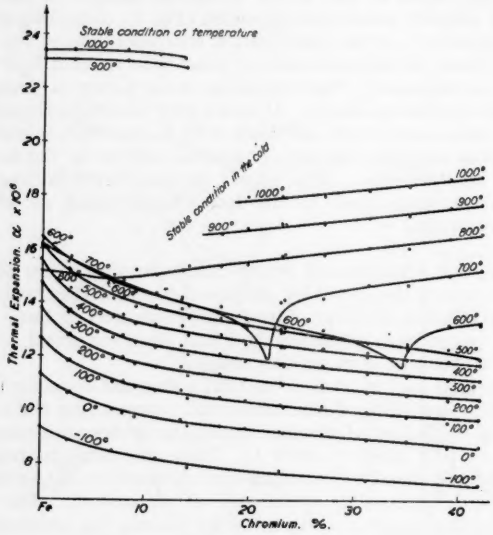


FIG. D.

touching on certain points which were still obscure, he would indicate his ideas concerning the experiments intended to clarify them. These three questions formed the object of the three points of his discussion.

(1) For his researches on the expansion of alloys carried out at the Aciéries d'Imphy he (Professor Chevenard) had made use of his recording differential dilatometer. The apparatus registered the difference between the expansions of two bars as a function of the expansion of one of them chosen as a standard. This standard was made of a nickel-chromium-tungsten alloy, known as "Pyros," which had been specially studied for this purpose. Its regular and reversible expansion measured the common temperature of the two specimens.

Naturally, the expansion of Pyros had been the object of numerous very carefully made determinations by means of a direct-reading dilatometer, which had been used either with liquid baths (liquid nitrogen, boiling water, &c.) or with a muffle-type electric resistance furnace. The Pyros was tested against fused silica and the temperature was measured at low temperatures by means of a precision thermometer and at high temperatures by a Le Chatelier couple. These experiments showed that, if large errors were to be avoided, the joint of the couple should be attached to the bar of Pyros or to a dummy bar of the same dimensions; failing this precaution, the temperature attained by the bar differed from that of the couple even in the case of very slow heating or cooling, on account of the enormous difference between their thermal capacities. The authors had certainly made a similar observation.

In the differential dilatometer, on the other hand, the temperature of the specimen under examination was measured indirectly by the temperature of the standard bar. An essential condition for the accuracy of the apparatus was, therefore, the equality of the temperatures of the two bars. This equality was assured by the symmetrical disposition of the bars in the furnace, by their identical dimensions, by the approximate equivalence of their thermal capacities and by the slowness of the variations of the temperature; in fact, it was attained to within 1°, except in the immediate neighbourhood of the $\alpha \rightleftharpoons \gamma$ transformation, on account of the heat of that reaction. In any case, that equality of temperature could be verified with the eye in the case of alloys undergoing reversible thermal transformations.

In effect, the deviations of temperature of the two specimens, due to systematic or accidental causes, changed their sign according to whether the temperature was rising or falling; in consequence, they placed the heating and cooling curves on one side or the other of the ideal curve which would correspond to a zero deviation. If, therefore, the curves registered by the dilatometer during heating and during cooling were almost exactly superimposed, this provided immediate proof that the bar of alloy studied and the Pyros standard had been at equal temperatures during the test.

The differential dilatometer was, therefore, in no sense less precise than the direct-reading dilatometer and it offered two very important advantages: It brought to light very small dilatometric peculiarities which, in a curve drawn point by point, might be mistaken for experimental errors; also, it afforded a great economy of time and manipulation.

Further, the authors' determinations and those of the writer had ultimately the same basis, because the differential dilatometer related the expansions to Pyros, which itself had been studied in relation to silica by means of a thermo-electric couple. It was, therefore, interesting to compare the results obtained in the two cases, and this he (Professor Chevenard) had done.

The authors represented their own results by the value of the average coefficient of expansion between 20° and 200°, 300° . . . 700°:

$$\alpha_m = \frac{L_\theta - L_{20}}{L_{20}(\theta - 20)},$$

L_θ representing the length of the bar at the temperature θ. He (Professor Chevenard) had preferred to use the true coefficient at all temperatures :

$$\alpha = \frac{1}{L_0} \cdot \frac{dL_\theta}{d\theta}$$

and the following were the reasons for this preference : The average coefficient between room temperature and a temperature θ depended on the properties of the material over a large temperature interval and was affected only very indirectly by the existence of a thermal peculiarity in that interval. The true coefficient α at 0°, on the

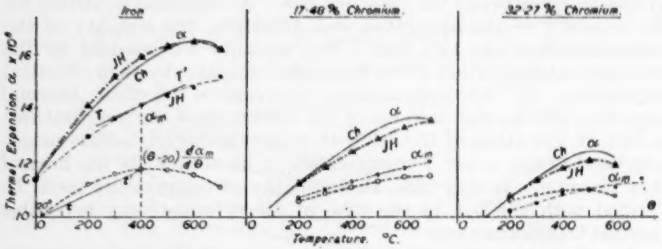


FIG. E.

other hand, depended only on the property of the alloy at the particular temperature θ.

Of course, the calculation of the true value of α presumed the evaluation of a derived figure. But as he (Professor Chevenard) had shown, *the graphical determination of a derivative was easy and exact when one had at one's disposal a recorded diagram which was clear, fine and devoid of all accidental bends*; such, precisely, were the curves traced by the differential dilatometer.

Now, in order to make comparison possible, it was very easy to convert values of the average coefficient α_m into values of the true coefficient α, by means of the following identity :

$$\alpha = \frac{1}{L_0} \cdot \frac{dL_\theta}{d\theta} \equiv \frac{L_{20}}{L_0}\left[\alpha_m + \frac{d\alpha_m}{d\theta}(\theta - 20)\right].$$

Therefore, in the diagrams in Fig. E, he (Professor Chevenard) had introduced for the temperatures 200°, 300° . . . 700°, the values for α_m taken from the authors' paper (p. 366) for iron and for two low-carbon alloys containing 17·48 and 32·27% of chromium.

In addition, in the first part of Fig. E, relating to iron, an additional point marked *G* corresponding to a temperature of 0° C. has been added. The ordinate of this point represented the average of two values of the true coefficient of dilatation of iron at 0° ($11{\cdot}33 \times 10^{-6}$ and $11{\cdot}45 \times 10^{-6}$) obtained by C. E. Guillaume, which would be found in the "Recueil des Constantes de la Société Française de Physique."

The points indicated by black circles were disposed sufficiently regularly to permit of the tracing of the α_m curve and the graphical derivation of this curve. A well-known construction, which consisted of drawing through the 20° co-ordinate a line *tt'* parallel to the tangent *TT'*, gave the points of the curve $(\theta - 20)d\alpha_m/d\theta$. Thus, all the elements were available for calculating the values of α, which in the diagram were represented by triangles.

Alongside the α curve thus deduced from the authors' results, and marked *JH* for that reason, he (Professor Chevenard) had reproduced the α curve deduced from his own diagram (Fig. D); the latter curve was marked *Ch.* It was easy to see that for iron and the two iron-chromium alloys *the results obtained in* 1927 *at Imphy and in* 1938 *at Stocksbridge differed very little.* The curves had very much the same shape, and the divergencies—small in any case—could be sufficiently well explained by the different origins of the metals studied and the differences in treatment. This good agreement Professor Chevenard hoped would suffice to convince the authors that the results obtained by means of the differential dilatometer were not less accurate than their own.

With regard to the rôle of carbon, one could *a priori* evaluate the direction and magnitude of its effect. In the absence of chromium, carbon with iron produced cementite, which, on account of its anomaly [1] corresponding to its magnetic transformation at 210°, diminished the expansion of steel. When chromium was added it gave rise to a more complex cementite, a solid solution of iron and chromium carbides; the Curie point of this cementite fell rapidly [2] to pass below zero temperature, and all trace of the anomaly of the complex carbide disappeared. For lower chromium contents the effect of carbon was, therefore, almost solely to withdraw from the alloy the chromium necessary for the formation of the complex cementite, but as, between 10 and 40% of chromium, the expansion varied slowly with the chromium content, the addition of carbon affected this expansion only very slightly.

(2) The dilatation curve of iron-chromium alloys revealed an anomaly corresponding to the magnetic transformation of the alloy.

[1] P. Chevenard, "Anomaly of Cementite in Annealed, Quenched and Semi-Quenched Carbon Steels," *Comptes rendus de l'Académie des Sciences,* 1917, vol. 164, p. 1005.

[2] P. Chevenard and A. Portevin, "Dilatometric Analysis of Alloys. General Ideas and First Applications to Cast Irons," *Revue de Métallurgie, Memoires,* 1925, vol. 22, p. 357.

On approaching the Curie point the curve was deflected downwards, and, once that point was passed, it tended to return to its original direction.

The existence of that phenomenon could be clearly seen in the

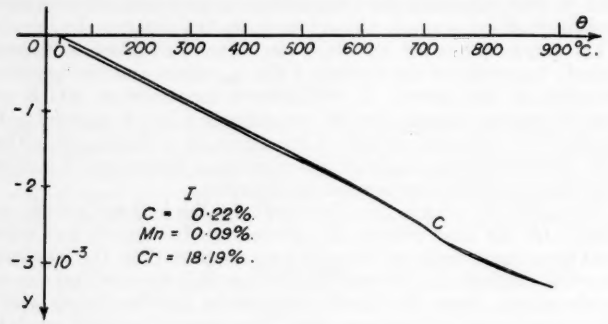


FIG. F.

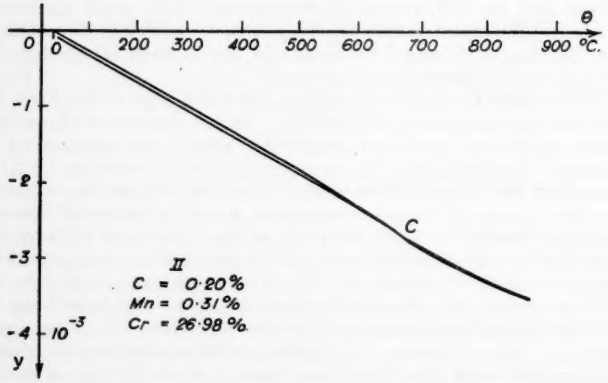


FIG. G.

five diagrams recorded by the differential dilatometer (I. to V., Figs. F to J). In these diagrams the heating and cooling curves were seen to be very close, sometimes almost coincident. The thermal effect—feeble in any case—due to the magnetic transformation of the iron-chromium alloy, therefore, did not sensibly affect the shape of these differential dilatation curves in the region of the Curie point, because the anomaly would be found with an almost identical

amplitude on the two curves recorded, one on heating and the other on cooling.

The dilatometric anomaly of α-iron at 760°, like that of the iron-

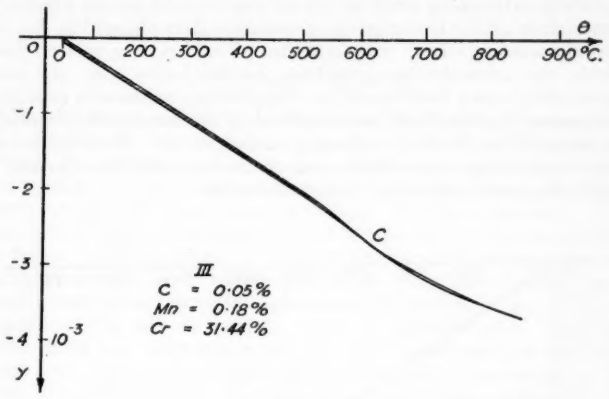


FIG. H.

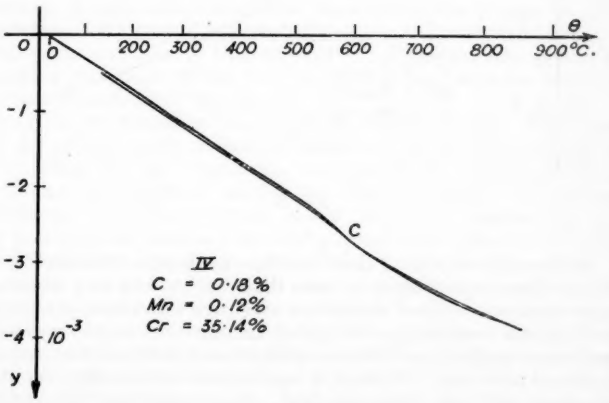


FIG. I.

chromium alloys, was *negative*, because on approaching the Curie point the expansion was decreased, which was followed by an increase as soon as that point was passed—hence the peculiarity, that was to say, the acute minimum in the isotherms for 600° and 700° which could be observed in Fig. D.

He (Professor Chevenard) had insisted on many occasions on the *absolutely general character of the dilatometric anomaly which accompanied the reversible thermal transformation of ferromagnetic materials.* In certain substances, such as α-iron, the iron-chromium alloys, the ferro-nickels of the Invar group, cementite, iron phosphide, &c., the anomaly was negative; in magnetite, nickel and the related ferro-nickels, the anomaly was positive. In the latter case, the curve representing α as a function of the temperature θ showed a maximum on approaching the Curie point instead of the minimum observed in the materials for which the anomaly was negative. The negative and positive anomalies were of the same character; only the sign and the amplitude varied according to the materials.

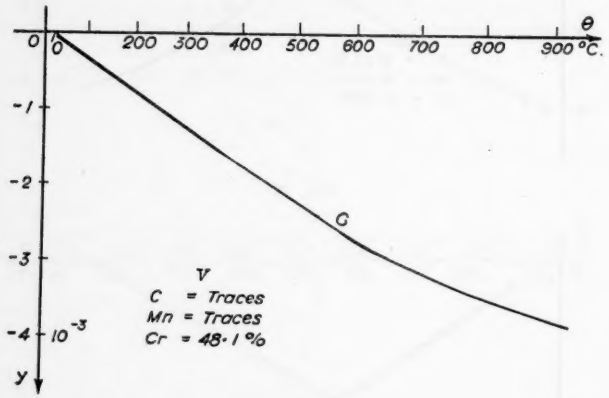


FIG. J.

(3) From the shape of the dilatation isotherms between 0% and 40% of chromium it could be seen that there would be a disordered region between 40% of chromium and pure chromium. In effect, the dilatation from 10% to 40% of chromium diminished very slowly, much less rapidly than if the α-iron/chromium solid solution followed the law of mixtures. Further, it was known that the alloys containing about 50% of chromium had, after quenching, properties—dilatation, Curie point, anomaly, &c.—differing from those which they possessed after annealing. Apparently, the atoms of iron and chromium were arranged in a " superstructure " in the alloys approximating in composition to FeCr; thermal agitation disturbed that superstructure when the temperature was raised and quenching did not give to it the freedom necessary for its reconstitution.

Professor Chevenard expressed the hope that this effect of the

various treatments might be the object of a detailed study and that the diagram of the dilatation of iron-chromium alloys might be extended right up to pure chromium in the near future.

AUTHORS' REPLY.

The AUTHORS, replying to Professor Svetchnikoff, wrote that the coincidence, at approximately 7½ atomic-% of chromium, between the minimum of the γ-loop determined by Adcock and a discontinuity in the lattice-parameter curve for the same alloys determined by Preston was interesting. In this connection, they noted that Professor Svetchnikoff had not plotted actual parameters, but "computed densities." They did not see the object of doing this, especially as these values were higher than the density figures actually determined upon the specimens; furthermore, the observed densities could not be said to show a discontinuity. Professor Svetchnikoff had then taken one set of values from the results of Austin and Pierce and plotted them to indicate a maximum on the curve of coefficients of thermal expansion corresponding to 7·6 atomic-% of chromium. (Incidentally, the expansion-scale on the right-hand side of Fig. A appears to have been reproduced wrongly.) However, Austin and Pierce also determined the γ-loop for their own series of alloys and reported it at approximately 9·6 atomic-% of chromium; in view of this, the authors suggested that it was not altogether justifiable to use their expansion results in the way that Professor Svetchnikoff had done.

In reply to Professor Chevenard, it would of course be realised that the authors made no direct reference either to his or to anyone else's values for the expansion coefficients of chromium alloys. They had the highest regard for the accuracy of Professor Chevenard's well-known work, but it might be pointed out that only part of their present research had been anticipated in Professor Chevenard's investigations. Also, their work on the effect of chromium was part of a much more comprehensive investigation into the effect of all the more common alloy additions to steel; so far as they knew, this had not yet been done systematically in any one laboratory, and it was therefore very desirable that they should be able to make direct comparison between all their own results.

They fully agreed with the remarks concerning the distinction between true and average coefficients of expansion. Their experience was that the engineer usually enquired for *average* coefficients from atmospheric temperature upwards, and therefore, as a company catering for industrial requirements, they normally reported their results in this way. Their experimental results of course also enabled them to calculate the *true* coefficients if required. It was interesting to see Professor Chevenard's comparison between derived

values from their results and his own earlier results for actual coefficients. Under the circumstances, the agreement could be regarded as satisfactory.

Concerning the association of a dilatometric anomaly with the Curie point, they could only repeat that they observed this phenomenon in the 32% chromium alloy, but it was not noticed in the others, although in one case (24½% chromium) it was specially looked for. From their experience, they were not ready to confirm the " absolutely general character " of the phenomenon as associated with the magnetic change point of ferromagnetic materials.

THE EXACT QUANTITATIVE ESTIMATION OF FERRIC OXIDE AND SULPHIDE SULPHUR IN BASIC SLAGS.*

By E. MAURER and F. HADERER
(School of Mines, Freiberg in Saxony).

Summary.

Brief references are made to the literature. The authors made twenty-two melts of synthetic sulphur-containing slags to determine the sulphide sulphur content, first without tin, and secondly with tin added to the dissolving acid; these showed that the error increases with the ferric oxide content of the slag. The latter was determined on the one hand indirectly by the method of O. Quadrat and on the other hand directly by that of W. Faber. In all the experiments the iron oxide content was found to be smaller when using the latter method than with the former, so that even an addition of mercuric chloride, as recommended by Faber, fails to prevent the nascent hydrogen sulphide produced by the acid solution from reacting with the iron oxide. It is further shown by direct experiment that the method of O. Quadrat does in fact yield perfectly accurate values for the iron oxide content.

A.—Introduction.

The exact quantitative determination of sulphur in ordinary steel by the acid evolution method is attended by no difficulty, but when this method is applied to slags which are capable of being dissolved in acids, its accuracy depends on whether ferric iron is present. Ferric iron and sulphide sulphur, when they occur together in acid-soluble slags, cannot be directly estimated with accuracy by the usual methods. The hydrogen sulphide produced has a reducing effect on the ferric iron, and, owing to the consequent production of ferrous iron, the ferric iron content is estimated too low. The same applies to the sulphide sulphur content in the presence of ferric iron. The relevant literature has been summarised by E. Diepschlag and E. Horn,[1] and E. Dittler [2] has shown how to correct the estimation of FeO in slag analyses by deducting from the FeO found an amount corresponding to the quantity of sulphide sulphur determined, on the assumption that all the sulphide sulphur present is consumed in the reducing process. O. Quadrat [3] has carried the sulphur balance further and has published a method for analysing open-hearth slags. Lately W. Faber [4] has described a direct method for determining the ferric iron in the presence of sulphide sulphur, depending on an addition of mercuric chloride which shall combine with the nascent hydrogen sulphide. The direct estimation of the

* Received November 15, 1937.

sulphide sulphur in the presence of ferric iron may also be carried out by the method of F. P. Treadwell,[5] in which the specimen is treated with metallic tin and concentrated hydrochloric acid. In the following are described determinations of the ferric iron on the one hand and on the other hand of the sulphide sulphur present in a series of synthetic slags, special attention being paid to the estimation of the magnitude of the errors arising. The melts were prepared in the course of work relating to the distribution of sulphur between pure iron and pure slags—a problem to which no further reference will be made here, and which has not yet been solved.

B.—Determination of the Sulphide Sulphur.

The sulphide sulphur may be estimated from the difference between the total sulphur content and the sulphate sulphur. The purpose of the present investigation, however, was to check the applicability of the usual acid evolution method to acid-soluble slags. According to the twelfth edition of Ledebur's well-known "Leitfaden für Eisenhütten-Laboratorien" (1925) the same method as is usual for steels could be directly applied to slags, though in the ninth edition of the same book (1911) a footnote on p. 156 expresses some misgiving that in the case of slags which contain iron in the form of ferric oxide a portion of the hydrogen sulphide may possibly be oxidised so that "somewhat too little" sulphur may be estimated.* In view of the determination of the ferric iron to be carried out at a later stage here, it was necessary first of all to clear up this discrepancy, and this was done on the synthetic slags already mentioned.

The experimental slags for the purpose were melted in carefully fired magnesia crucibles as supplied by the Deutsche Gold- und Silber-Scheideanstalt under the name of "Degussa" sintered magnesia crucibles.

The materials used for the melts were:

(1) Iron (ferrum reductum, Merck) containing 0·2% of silicon and 2·16% of oxygen, corresponding to 11·75% of FeO and estimated by the hydrogen reduction method.

(2) Ferrous sulphide containing 29·30% of sulphur, granulated (Merck).

(3) Ferrous oxide (Merck) containing 43·08% of FeO, 54·61% of Fe_2O_3, 0·08% of SiO_2, 0·19% of iron, 0·06% of carbon, and giving 1·89% loss on ignition *in vacuo*.

(4) Silica, chemically-pure precipitated, powdered (loss on ignition 13·02%).

(5) Calcium oxide (Kahlbaum's "for analysis") with a varying loss on ignition.

These materials were well mixed and were pressed into briquettes under a pressure of 3–4 metric tons per sq. cm. in order that the greatest possible weight might be introduced into the crucibles;

* According to a suggestion by O. Quadrat.[3]

they were then melted in a muffle furnace and allowed to cool in air, after which the crucibles were broken and the metal regulus was removed. The slag was carefully separated from the fragments of the crucible and reduced to a fine powder, using a mortar and sieve. Altogether 22 synthetic slags were examined, comprising :

(1) Six pure FeO slags.
(2) Eight CaO–FeO slags.
(3) Four SiO_2–FeO slags.
(4) Four CaO–SiO_2 slags.

(*a*) *Methods of Chemical Analysis.*

The examination of the slags covered the quantitative determination of silica, calcium oxide, magnesium oxide, sulphide sulphur (in some cases also the total sulphur and the sulphate sulphur), the total iron content and its two oxides. The estimations of the silica, calcium oxide, magnesium oxide, total iron, total sulphur and sulphate sulphur were carried out in the usual way, so that no further details need be given here.

For the *direct determination of the sulphide sulphur* in the slags the tin method, already mentioned, was applied in a somewhat modified form as given by Treadwell for the determination of sulphide sulphur in insoluble sulphides.

For this estimation 2–3 g. of the finely-divided slags and equal weights of tin powder were introduced into a sulphur-generating apparatus and were dissolved in 100 c.c. of concentrated hydrochloric acid. The hydrogen sulphide so produced was absorbed in a receiver containing 40 c.c. of cadmium acetate dissolved in acetic acid, where it was converted into yellow cadmium sulphide. (The solution consisted of 25 g. of cadmium acetate in 200 c.c. of glacial acetic acid, made up with water to 1 litre and filtered.) When dissolving the specimen in hydrochloric acid, at first only gentle heat was applied so as to avoid premature distillation of the hydrochloric acid, but towards the end of the solution process the heat was increased until the water in the washing receiver began to boil, in order to expel any absorbed hydrogen sulphide. The cadmium acetate receiver was removed at the moment when condensed water was observed to be produced in the horizontal portion of the connecting tube. On completion of the process the cadmium sulphide was converted into copper sulphide by an addition of 5 c.c. of copper sulphate solution (120 g. of copper sulphate dissolved in a mixture of 880 c.c. of water and 120 c.c. of sulphuric acid (sp. gr. 1·84) and filtered).

The copper sulphide was filtered off as soon as possible, washed ten times with hot distilled water, and immediately ignited carefully in a weighed porcelain crucible. It was heated at first gently and then strongly for the last five minutes, in order both to avoid reduction to metallic copper by carbon from the filter paper and to convert any copper sulphate formed into copper oxide. One gramme of copper oxide corresponds to 0·4029 g. of sulphur.

The tin powder rapidly dissolves in the hydrochloric acid, producing stannous chloride which at once reduces the trivalent iron going into solution; hence no reaction between ferric chloride and hydrogen sulphide, yielding elementary sulphur, can occur, and no error in the sulphide sulphur estimation can arise from this cause. A further product of the solution of the tin is hydrogen in a nascent state, which has a powerful reducing action, and which, therefore, at the same time prevents any oxidising effect of the oxygen in the air before the steam produced by boiling can so act.

The tin powder employed must be checked for freedom from sulphur in order that there may be no error on this account.

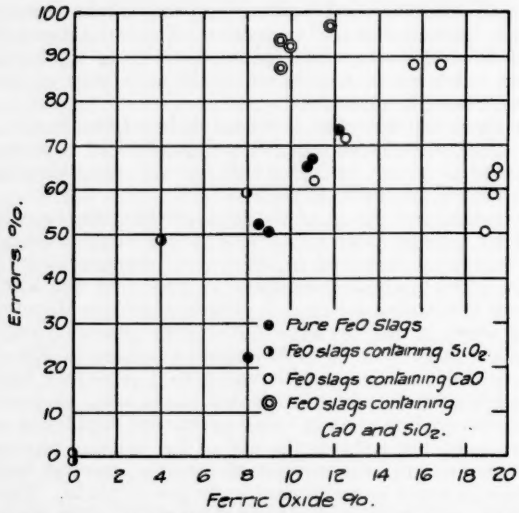


FIG. 1.—Errors in the Estimation of the Sulphur Content in Slags by the Solution Method without the presence of metallic tin, in relation to the true Fe_2O_3 content of the slag.

(*b*) *Results of the Sulphide Sulphur Estimation.*

Apart from the direct estimation of the sulphide sulphur by the tin method, a determination was made of that portion of the sulphide sulphur which is precipitated in the cadmium acetate receiver as cadmium sulphide on dissolving in hydrochloric acid *without* the presence of metallic *tin*. The difference between this amount and the total sulphide sulphur content as determined directly represents the weight of sulphur which separates out in the elementary form in the solution process, and which corresponds

to the amount of ferric iron reduced. This error in estimating the sulphide sulphur by the usual method, expressed as a percentage in relation to the content of ferric oxide in the slag, is indicated in Fig. 1, the figures being taken from columns 7 and 10 in Table I. Despite a good deal of scattering of the results, it is clearly evident how the error which arises in estimating the sulphide sulphur by the usual method *without* tin increases with the ferric oxide content of the slag. It appears from this that the amount of sulphur

TABLE I.—*Errors in Estimation of Sulphide Sulphur by the Acid Evolution Method without Metallic Tin in the Presence of Ferric Iron.*

No.	SiO_2. %.	CaO. %.	MgO. %.	Total Fe. %.	True Values according to Quadrat.		Sulphide Sulphur (Determined without Tin). %.	Sulphide Sulphur (Tin Method). %.	Error in Estimation without Tin. %.	Total Sulphur (Gravimetric). %.	Sulphate Sulphur (by Difference). %.
					FeO. %.	Fe_2O_3. %.					
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**
21	...	...	1·82	75·33	87·22	10·87	0·1789	0·5289	66·20	N.d.	N.d.
22	...	...	1·28	75·64	87·90	10·69	0·1902	0·5422	65·00	N.d.	N.d.
36	...	...	5·85	72·16	85·86	8·03	0·5596	0·7189	22·55	N.d.	N.d.
37	...	...	0·70	76·10	87·12	12·06	0·1499	0·5545	72·90	0·5852	0·0307
54	...	...	8·21	70·18	82·65	8·52	0·3120	0·6000	52·0	N.d.	N.d.
55	...	...	8·00	70·34	82·48	9·00	0·3385	0·6851	50·6	N.d.	N.d.
26	...	10·11	3·33	65·80	69·49	16·92	0·0443	0·3587	87·65	0·3835	0·0248
27	...	8·20	1·94	68·36	73·94	15·61	0·0752	0·5973	87·50	N.d.	{0·0398* / N.d.
29	...	1·09	1·00	75·48	85·89	12·43	0·1834	0·6432	71·50	N.d.	N.d.
30	...	1·08	1·04	74·74	86·28	11·01	0·2165	0·5634	61·70	N.d.	N.d.
34	...	33·07	1·08	48·40	44·93	19·35	0·2929	0·7805	62·40	N.d.	N.d.
40	...	30·64	1·66	50·60	47·84	19·26	0·3332	0·7758	58·00	0·7820	0·0062
42	...	22·73	1·63	57·78	56·90	19·42	0·3312	1·0307	64·20	N.d.	N.d.
47	...	19·01	N.d.	58·45	58·28	18·86	0·3788	0·7624	50·30	N.d.	N.d.
43	15·81	...	8·61	56·07	65·51	8·10	0·2547	0·6173	58·80	0·6481	0·0308
45	29·88	...	21·20	39·69	51·04	0	0·5756	0·5804	0·87	0·6384	0·0580
48	44·73	...	11·23	34·18	43·96	0	0·3369	0·3337	−0·94	0·3652	0·0315
49	32·73	...	24·05	33·70	39·64	4·15	0·1451	0·2834	48·80	N.d.	N.d.
50	9·08	17·39	23·25	36·93	38·58	9·96	0·0202	0·2611	92·20	N.d.	N.d.
51	12·45	19·13	2·31	49·00	52·48	11·80	0·0215	0·5625	96·20	N.d.	N.d.
52	12·83	30·43	1·94	41·30	44·71	9·50	0·0202	0·3192	93·30	0·3775	{0·0521* / 0·0583
53	6·08	14·63	N.d.	58·51	66·68	9·52	0·0457	0·3079	87·00	N.d.	N.d.

* Sulphate sulphur estimated gravimetrically from hydrochloric acid solution.
N.d. = not determined.

determined is not merely " somewhat too low " as suggested in the ninth edition of Ledebur's " Leitfaden für Eisenhütten-Laboratorien," but that quite considerable errors may arise. Such errors are indeed so important that, referring, for instance, to the experiments indicated in Fig. 2, which relate to the distribution of sulphur between metal and FeO slags, if no account is taken of the oxidation of the hydrogen sulphide by any ferric iron present, the distribution curve may actually be reversed.

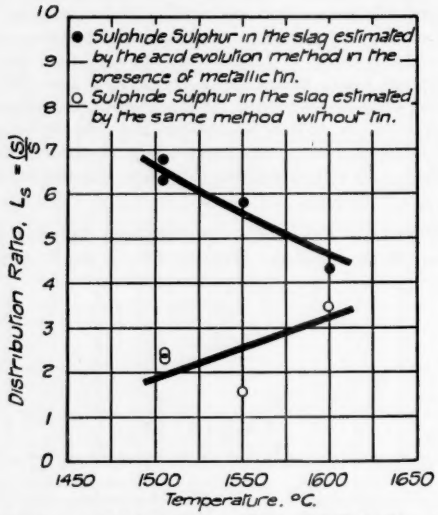


FIG. 2.—Distribution of Sulphur between Iron and FeO Slags in Relation to the Temperature. (Melted in MgO crucibles; temperature measured by calibrated platinum/platinum-rhodium thermocouple.)

C.—ESTIMATION OF THE FERRIC IRON IN SLAGS CONTAINING SULPHIDE SULPHUR.

(*a*) *Methods of Chemical Analysis.*

It has already been mentioned above that when specimens of slag are dissolved in hydrochloric acid the nascent hydrogen sulphide reacts with the ferric iron going into solution, with the result that elementary sulphur is separated out, and reduction to ferrous iron takes place; hence, not only is the estimation of sulphur invalidated but also the directly-titrated ferrous iron in the solution appears too high, and consequently the ferric iron calculated by difference from the total iron content works out too low.

Hitherto no account has been taken of this circumstance in analyses of basic open-hearth slags recorded in the literature. As already mentioned at the beginning of this paper, the earliest reference to it was made by O. Quadrat [3] when he considered the true quantities of the two oxides of iron present in slag in the form of a sulphur balance. Quadrat first determined the total iron in particular specimens by the Reinhardt-Zimmerman method, the total sulphur content, after oxidation by bromine, as barium sulphate, and the sulphate sulphur from a solution of the slag in hydrochloric acid; the difference between the total sulphur content and

the sulphate sulphur then gave the amount of sulphide sulphur actually present. He next decomposed a specimen of slag in a hot mixture of 100 c.c. of sulphuric acid (1 : 5) and 5 c.c. of concentrated hydrochloric acid (with the addition of a few glass balls) in a current of carbon dioxide according to the usual method of Schulte. In this way a portion of the resulting hydrogen sulphide reduced an equivalent quantity of ferric iron. The remainder of the hydrogen sulphide was absorbed in cadmium acetate and estimated by the usual method as remaining sulphide sulphur. The difference between the total sulphide sulphur and the remaining sulphide sulphur gave a measure of the amount of sulphur which, in the form of hydrogen sulphide, reduced the ferric iron in the solution to ferrous iron. This quantity, after calculation to the corresponding amount of iron, represented the " correction " for the actual content of bivalent and trivalent iron; according to the equation

$$2FeCl_3 + H_2S = 2HCl + 2FeCl_2 + S,$$

one atom of sulphur corresponds to two atoms of iron.

According to a private communication dated 13th May, 1937, from O. Quadrat to one of the authors (E. Maurer), the figures in the column headed " FeO, Titrated Direct " in Table I. of his paper [3] as printed in the *Journal of the Iron and Steel Institute* are not right, having been incorrectly copied from the paper appearing in *Chemické Listy pro Vědu a Průmysl* for 1920. In this letter Quadrat gives the following example of the calculation for slag No. 1 in the Table in question:

Total sulphur	0·3530%
Sulphate sulphur	0·0270%
Total sulphide sulphur, by difference	0·3260%
Remaining sulphide sulphur, from cadmium sulphide	0·1035%
Sulphide sulphur consumed in reduction of the iron	0·2225%
Total iron	8·92%
Directly titrated ferrous iron	7·355%
Ferric iron, by difference	1·565%
Ferric iron reduced by hydrogen sulphide	0·775%
True values: Ferrous iron	6·58%
Ferric iron	2·34%

The proposal made by Quadrat that a sulphuric acid solution should be used is not easy to carry out when the lime content is high, because the calcium sulphate so produced coagulates and encloses undissolved particles of slag, thereby limiting the effect of the acid. Either the amount of hydrochloric acid added must be increased, or nothing but hydrochloric acid must be used for decomposing the slag from the beginning; then neither the sulphur balance nor the direct ferrous iron titration is affected, so long as the manganese sulphate solution has been added according to Reinhardt's method in sufficient quantity to the greatly diluted solution. Nevertheless, the FeO estimations recorded in Table II. were made by Quadrat's method in sulphuric acid solution, and only in the

TABLE II.—*Estimation of Ferrous and Ferric Oxides in Sulphur-Bearing Slags.*

No.	SiO_2. %.	CaO. %.	MgO. %.	FeO in Solution, according to Estimation of Sulphide Sulphur by Direct Titration without Tin.			Total Sulphur (Gravimetric). %.	Sulphide Sulphur (Tin Method). %.	Sulphate Sulphur. %.	Sulphide Sulphur (Estimated without Tin). %.	Error in Column 11. %.	Sulphide Sulphur used in Reduction of Ferric Iron. %.	Ferric Iron Reduced. %.	Corresponding FeO. %.	Corresponding Fe_2O_3. %.	True Values according to Quadrat's Stoichiometric Correction.		Values according to Faber.	
				Total Fe. %.	FeO. %.	Fe_2O_3. %.										FeO. %.	Fe_2O_3. %.	FeO. %.	Fe_2O_3. %.
1.	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**	**9.**	**10.**	**11.**	**12.**	**13.**	**14.**	**15.**	**16.**	**17.**	**18.**	**19.**	**20.**
21	...	...	1·82	75·33	88·85	9·05	N.d.	0·5289	N.d.	0·1789	66·20	0·3500	1·219	1·630	1·823	87·22	10·87	89·70	8·05
36	...	...	5·85	72·16	86·60	7·20	N.d.	0·7189	N.d.	0·5596	22·55	0·1593	0·556	0·742	0·83	85·86	8·03	86·83	6·72
37	...	...	0·70	76·10	89·00	9·95	0·5852	0·5545	0·0307	0·1499	72·90	0·4096	1·409	1·884	2·105	87·12	12·06	89·93	8·93
26	...	10·11	3·33	65·80	70·95	15·28	0·3835	0·3587	0·0248	0·0443	87·65	0·3144	1·094	1·463	1·635	69·49	16·92	70·95	15·23
34	...	33·07	1·08	48·40	47·20	16·84	N.d.	0·7805	N.d.	0·2929	62·50	0·4876	1·695	2·27	2·504	44·93	19·35	47·62	16·30
40	...	30·64	1·66	50·60	49·90	16·95	0·7820	0·7758	0·0062	0·3332	58·00	0·4426	1·541	2·061	2·305	47·84	19·26	51·04	15·65
42	...	22·73	1·63	57·78	60·45	15·46	N.d.	1·0357	N.d.	0·2740	73·90	0·7617	2·65	3·55	3·96	56·90	19·42	61·00	14·09
47	...	19·01	N.d.	58·45	61·00	15·80	N.d.	0·7624	N.d.	0·1793	76·45	0·5831	2·03	2·72	3·065	58·28	18·86	61·48	15·26
49	32·73	...	24·05	33·70	40·65	3·02	N.d.	0·2834	N.d.	0·0672	76·20	0·2162	0·754	1·008	1·127	39·64	4·15	40·20	3·57
50	9·08	17·39	23·25	36·93	39·70	8·70	N.d.	0·2611	N.d.	0·0202	92·20	0·2409	0·839	1·122	1·255	38·58	9·96	39·40	9·31
51	12·45	19·13	2·31	49·00	55·00	8·98	N.d.	0·5625	N.d.	0·0215	96·20	0·5410	1·885	2·522	2·820	52·48	11·80	54·20	9·87
52	12·83	30·43	1·94	41·30	46·10	7·94	0·3775	0·3192	0·0583	0·0202	93·30	0·2990	1·042	1·393	1·556	44·71	9·50	45·50	8·54
53	6·08	14·63	N.d.	58·51	67·90	8·16	N.d.	0·3079	N.d.	0·0457	87·00	0·2622	0·9135	1·222	1·365	66·68	9·52	67·20	8·68

N.d. = not determined.

case of samples Nos. 34, 40 and 52, which contained a larger quantity of lime, was the quantity of concentrated hydrochloric acid increased from 5 c.c. to 15 c.c.

As already mentioned above, another method for directly estimating both ferrous and ferric iron in the presence of sulphide sulphur has been described by W. Faber[4]; he proposed that, as the first attempts to combine the nascent hydrogen sulphide straight away with copper or silver ions had been unsuccessful, this combination might be brought about by ensuring the presence of a large excess of mercuric chloride in 5% solution. By comparative titrations of artificially prepared mixtures he established that it was possible by this method to estimate directly both of the iron oxides in slags containing sulphide sulphur. He also emphasised that this method was capable of yielding useful results only when the contents of sulphur and of ferric iron were not too high; the iron oxide contents in the lead slags examined by him lay between 2 and 17%, and the sulphide sulphur content generally between 2 and 5%.

Faber's method is as follows: The powder to be analysed (0·4 g.) is placed in an Erlenmeyer flask and the air is displaced by carbon dioxide; then 40 c.c. of 5% mercuric chloride solution and 40 c.c. of hydrochloric acid (1 : 2) are added. The vessel is closed by a water seal and the specimen is dissolved by slow heating on the sand-bath. The vessel is next cooled rapidly by placing it in cold water, and a Reinhardt-Zimmerman titration is at once carried out.

(*b*) *Results of the Iron Oxide Estimations.*

Table II. gives the results of the analytical estimation by both the methods described. As an example, the stoichiometric correction of the results of the ferric iron estimation in slag No. 21 is given below:

Sulphide sulphur directly determined by the tin method .	0·5289%
Remaining sulphide sulphur (determined in the absence of tin)	0·1789%
Sulphide sulphur consumed in the reduction of iron . .	0·3500%
Reduced iron $= 0{\cdot}3500 \times \frac{2 \times 55{\cdot}84}{32{\cdot}07} =$	1·219%
Corresponding FeO $= 0{\cdot}35 \times \frac{2 \times 55{\cdot}84}{32{\cdot}07} \times 1{\cdot}287 =$ . .	1·630%
Corresponding $Fe_2O_3 = 0{\cdot}35 \times \frac{2 \times 55{\cdot}84}{32{\cdot}07} \times 1{\cdot}43 =$ . .	1·823%
Total iron	75·33%
Directly titrated: FeO	88·85%
Fe_2O_3	9·05%
Actual values: FeO $= 88{\cdot}85 - 1{\cdot}63 =$ . . .	87·22%
$Fe_2O_3 = 9{\cdot}05 + 1{\cdot}823 =$ . . .	10·87%

Thus the results according to Quadrat are:

FeO = 87·22% and Fe_2O_3 = 10·87%, as against
FeO = 89·70% and Fe_2O_3 = 8·05%, according to Faber.

Similar differences occur in the case of the other slags, as may be seen in the last four columns of Table II.

In order to obtain a better understanding of the chemical reasons for the difference obtained in determining the ferrous iron by the two methods, and finally to decide which method gives the better results, the following series of experiments was carried out on the CaO–FeO slag No. 26.

Using the tin method, the amount of sulphide sulphur present in a slag specimen weighing 5 g. was found to be 0·0174 g. On decomposing another specimen of 5 g. without the presence of metallic tin, the sulphur precipitated as cadmium sulphide was determined as 0·0031 g. The difference between these two quantities represents that part of the sulphide sulphur which was utilised in the reduction of the trivalent iron; it must occur as elementary sulphur in the slag solution, and amounts to 0·0174 — 0·0031 = 0·0143 g. From column 13 in Table II., the quantity of sulphide sulphur in the 5-g. specimen works out at $0{\cdot}3144 \times \frac{5}{100} = 0{\cdot}0157$ g. In the experiment carried through without the addition of tin, the contents of the decomposition flask were filtered through a glass filter crucible; the residue was washed with water until no iron reaction or chlorine reaction could be detected, dried in an electric drying oven at a constant temperature of 102° C., and then weighed. It was then extracted eight times with carbon bisulphide in a Soxhlet automatic-syphon extractor. The glass filter crucible was then again dried and the weight lost by the residue in the filter was found to be 0·0155 g. The elementary sulphur extracted from the residue was now dissolved in the carbon bisulphide contained in the Soxhlet flask. In order that the process might be checked as closely as possible, the carbon bisulphide, amounting to 150 c.c., was heated to 75–78° C. on a water-bath and distilled off. On subtracting the " blank " for the same quantity (150 c.c.) of the carbon bisulphide, which amounted to 0·0026 g., the elementary sulphur remaining was found to be 0·0149 g. This was brown in colour and burned with a blue flame, smelling of sulphur dioxide. The quantitative combustion of this, allowing for the " blank " already determined, gave a weight of 0·0154 g. This experimental result shows that the sulphide sulphur consumed in the reduction of the ferric iron in the slag solution remains quantitatively as elementary sulphur in the solution. Quadrat's stoichiometric correction of the ferrous iron directly titrated in the solution for this part of the sulphide sulphur, is therefore found to be correct.

A corresponding investigation was made in relation to the Faber method as follows : 5 g. of slag No. 26 were suspended in 100 c.c. of mercuric chloride solution and then dissolved in 100 c.c. of hydrochloric acid (1 : 2). On passing the gases produced through a cadmium acetate receiver no cadmium sulphide was precipitated, showing that the whole of the sulphide sulphur had been decomposed and retained in the solution. The further question now arose as

to whether the hydrogen sulphide produced during solution of the specimen had at once combined quantitatively with the mercuric chloride to form mercuric sulphochloride, or whether at the same time partial reduction of the ferric iron had taken place also. To settle this point the yellowish-white precipitate was filtered off in a filter crucible, dried at 98° C., and weighed, giving a weight of 0·1050 g. It was then extracted with carbon disulphide in the Soxhlet apparatus. On again drying the loss of weight of the precipitate on the filter was found to be 0·009 g. On driving off the extraction medium, and allowing for the sulphur already present in the carbon disulphide (a " blank " of 0·0026 g. for 150 c.c.), 0·0094 g. of elementary sulphur was found, which figure was not altered on burning the residue quantitatively. The residue again had a yellowish-brown colour and burned with a blue flame with a distinct smell of sulphur dioxide.

This result indicates that when using the method proposed by Faber for the direct estimation of ferrous iron, only 47·8% of the sulphide sulphur in the slag is converted into mercuric sulphochloride, while 52·2%, in the form of hydrogen sulphide, goes to the reduction of the ferric iron.

In order to establish the part played by the mercuric sulphochloride in the carbon bisulphide extraction and also its behaviour towards potassium permanganate solution, it was prepared in a pure form by the method of Gmelin-Kraut,[6] by passing hydrogen sulphide gas, dried by passage over calcium chloride and phosphorus pentoxide, into a solution of 5 g. of mercuric chloride in 100 c.c. of acetone, until black mercuric sulphide began to form in the lower portion of the inlet tube. The yellowish-white precipitate was then filtered off on glass wool in a filter crucible and dried. A portion weighing 0·1055 g. was extracted with carbon bisulphide; no production at all of elementary sulphur from the mercuric sulphochloride could be established.

The same weight (0·1055 g.) of mercuric sulphochloride was titrated with $N/10$ potassium permanganate solution, the acidity and the amount of manganese-sulphate/phosphoric-acid solution being the same as those employed in ferrous iron titrations; 1·3 c.c. of this potassium permanganate solution was consumed. The end-point was indefinite, and the precipitate was dark in colour.

The process for the direct titration of ferrous iron as described by W. Faber suffers, then, from two defects. Even though a part of the hydrogen sulphide produced when the slag is dissolved in hydrochloric acid combines with the mercuric chloride, so that the quantity of ferrous iron found approximates to that given by direct titration, yet the remainder of this hydrogen sulphide will exert a reducing effect on the ferric iron passing into solution. Also, the mercuric sulphochloride formed itself consumes potassium permanganate in the titration, and this gives rise to a further increase in the quantity of ferrous iron estimated by direct titration. These

disturbing influences will increase with the amount of sulphide sulphur contained in the slag.

D.—Conclusion.

It thus appears that the process of W. Faber for the direct estimation of ferric iron in sulphide-bearing slags is not practicable, but the method of O. Quadrat gives perfect results.

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(1) E. Diepschlag and E. Horn : *Archiv für das Eisenhüttenwesen*, 1930–31, vol. 4, pp. 375–382 (*see* in particular pp. 376–377).
(2) E. Dittler : *Zeitschrift für anorganische Chemie*, 1926, vol. 158, pp. 264–276 (*see* in particular pp. 274–275).
(3) O. Quadrat : *Journal of the Iron and Steel Institute*, 1930, No. II., pp. 175–190.
(4) W. Faber : *Zeitschrift der chemischen Mineralogie, Petrografie, Geologie und Bodenkunde*, 1935, vol. 10, pp. 67–115.
(5) F. P. Treadwell : " Analytische Chemie," 13th edition, vol. II., p. 315. Leipzig and Vienna, 1927 : F. Deuticke.
(6) Gmelin-Kraut : " Handbuch der anorganischen Chemie," 7th edition, vol. 5, Part II., p. 732. Heidelberg, 1914 : Verlag Chemie G.m.b.H.

CORRESPONDENCE.

Dipl.-Ing. ERICH STENGEL (Research Laboratories, Fried. Krupp A.-G., Essen) wrote that the direct estimation of the ferrous oxide content of sulphur-bearing slags by solution in the presence of mercuric chloride, as proposed by W. Faber, was not altogether unknown. Some years ago, in an investigation designed to clear up some problems connected with the work of reduction in the blast-furnace, the ferrous-oxide content of sulphur-bearing slags was determined in his laboratory by that method. Nevertheless, duplicate determinations were not in very close agreement; however, as no better method was available, these variations had to be put up with.

Comparative tests carried out later on normal basic open-hearth slags by O. Quadrat's method and with mercuric chloride showed that the ferrous-oxide figures obtained by Quadrat's procedure were always lower, which agreed with the results of the present authors' work. The differences were not always very large, as was shown in the examples included in Table A. Nevertheless, such values should not deceive one concerning the lack of dependability of a method. It was therefore much to be welcomed that the authors, besides determining the complete utility and accuracy of Quadrat's method, had also demonstrated the sources of error in Faber's method, so that a clear idea was now available concerning the possibility of determining with precision the ferrous-oxide stages in sulphur-bearing slags.

With regard to the actual carrying-out of Quadrat's procedure,

TABLE A.

No.	FeO in Solution when Determining the Sulphide Sulphur by Direct Titration without Tin.			Total Sulphur. %	Sulphide Sulphur (Tin Method). %	Sulphide Sulphur, without Tin. %	Sulphide Sulphur consumed in Reduction of Ferric Iron. %
	Total Fe. %	FeO. %	Fe_2O_3. %				
1	11·26	11·71	3·12	0·31	0·30	0·20	0·10
2	9·34	10·65	1·54	0·30	0·29	0·13	0·16

No.	Ferric Iron Reduced. %	Corresponding FeO. %	Corresponding Fe_2O_3. %	True Values, with Quadrat's Correction.		Values by Faber's Method.	
				FeO. %	Fe_2O_3. %	FeO. %	Fe_2O_3. %
1	0·35	0·45	0·50	11·26	3·62	11·50	3·35
2	0·56	0·72	0·80	9·93	2·34	10·07	2·19

he would add that, according to his own experience, the authors' suggestion that, with slags carrying higher contents of lime, solution should be effected with hydrochloric acid only, was to be recommended.

AUTHORS' REPLY.

The AUTHORS, in reply, desired to offer to Dipl.-Ing. Stengel their best thanks for his contribution. This formed a valuable supplement to their own paper.

COMMUNICATION.[1]

NOTE ON BRITTLE NICKEL STEEL.

By The Late Dr. J. E. STEAD, F.R.S.

(Figs. 2 to 4 = Plate XXVIII.)

Explanatory Introduction.—On September 27, 1920, Mr. H. S. Kipling sent to Dr. Stead a specimen of a shaft made of nickel case-hardening steel. It had been forged and heat-treated. It broke when dropped on the floor, yet a few inches further along it was extremely tough, as could be seen by the fracture at the other end; it had a coarse granular fracture running through a much finer structure. The composition of the metal was as follows:

Carbon . . .	0·15%	Manganese . . .	0·29%
Silicon . . .	0·12%	Nickel . . .	5·94%
Sulphur . . .	0·041%	Chromium . . .	0·06%
Phosphorus . . .	0·020%		

On November 9, 1920, the Note reproduced below was sent to Mr. Kipling by one of Dr. Stead's assistants, who mentioned that it was in draft form only, and added that Dr. Stead would like to know whether Mr. Kipling had any objection to its publication by Dr. Stead in, say, the *Journal of the Iron and Steel Institute*. Mr. Kipling readily agreed; for various reasons, however, it was not incorporated in Dr. Stead's paper of 1921,[2] and the illness which finally caused his death prevented him from putting his intention into effect. So far as is known, the Note has never been published.

In submitting the Note Mr. Kipling feels that it would be a pity if any fragment of Dr. Stead's work should be lost—a view in which the Council of the Iron and Steel Institute concur. The Note is printed without alteration, except for the addition of figure numbers to make the references to them clear.

The sample was sent to me by Mr. H. S. Kipling on September 27th, 1920.

It consisted of a broken shaft.

It is a nickel case-hardening steel.

The shaft broke when it was dropped on the floor with a coarse intercrystalline fracture at the thick end. The surface of the fracture was much rusted when received, therefore saw cuts were made at *A* and *B* (Fig. 1) and fresh fractures made. These were photographed after magnifying about 4 diameters (Figs. 2 and 3).

The new fracture at *A* was entirely intercrystalline, not a single crystal had broken. The size of the crystal sides varied between

[1] Received March 23, 1938.

[2] *Journal of the Iron and Steel Institute*, 1921, No. I., p. 271.

0·05 and 0·2 inches in diameter. They all had a frosted appearance as if they had been sand blasted.

The fracture at *B* was quite different from that at *A*, one third of the surface was intercrystalline, two thirds finely crystalline. At the intercrystalline portion the size of the crystals was half to one third as large as those at *A*.

The fracture at *C* was exceedingly fine.

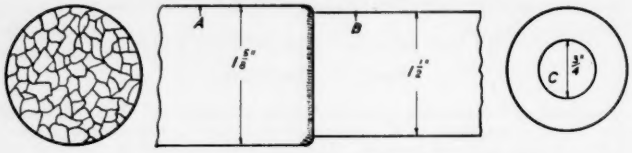

FIG. 1.—Sketch of the Shaft.

A section $\frac{3}{16}$ inch thick cut from the thick end *A* was polished and etched with various reagents, but in no case could the junctions of the large grains be detected. The structure was normal for properly treated nickel steel. There were the characteristic lines parallel to the length of the bar. After failure to detect any fault or intergranular weakness the specimen $\frac{5}{8}$ inch in length was bent in a press. It broke with the slightest deflection. This was photographed at 50 diameters (Fig. 4).

It shows the coarse intergranular fracture and fine crystals.

For some reason or other—probably high heating in my opinion—the crystals were initially larger at one end than the other. That the whole piece had been afterwards heated to the proper temperature to refine and break up the crystals but the original crystal faces had remained in a slightly coherent condition. What is the character of the metal at the intercrystalline junctions and the normal surfaces of the fine grained fracture?

BRITTLE NICKEL-STEEL SHAFT.

FIG. 2.—Fracture at *A* in Fig. 1. × 4. FIG. 3.—Fracture at *B* in Fig. 1. × 4.
(Reduced to three-quarters linear in reproduction.)

FIG. 4.—Fracture of Specimen from the Thick End *A* of Fig. 1. × 50.

[*Stead.*
[*To face p.* 398 P.

UNIV. OF MICH.

THE APPLICATION OF TIME STUDY TO ROLLING MILLS.

By the ROLLING MILL COMMITTEE of the Iron and Steel Industrial Research Council.

This Report was published as Special Report No. 20; it was presented at the Annual Meeting of the Iron and Steel Institute held in London on May 6, 1938. The discussion and Committee's reply follow the summary below.

Summary.

This Report describes a series of investigations carried out with the idea of extending the use of time study in iron and steel works. Three mills were examined :

(*A*) A steam-driven 36-in. cogging mill.
(*B*) An electrically-driven 36-in. cogging mill.
(*C*) An electrically-driven 30-in. slabbing mill.

By applying standards based on time studies, an efficiency index was established by means of which the performances of each mill could be compared. From a study of the Report the following facts are made apparent: (1) The application of research into problems of production control, conducted principally by means of the stop-watch, will provide reliable standards of performance and show how plant utilisation can be increased. (2) A considerable difference was found to exist as between the best tonnage that could be produced and what was in fact turned out. (3) Time studies have brought to light the necessary requirements to secure the best output under optimum conditions and a reliable method of comparing outputs obtained from time to time, irrespective of the ingot size and finished section.

No attempt, however, has been made to compare the performance of the very dissimilar mills examined.

DISCUSSION.

Mr. E. C. Evans (London), in presenting the Report, expressed his regret that Mr. H. E. Wright had been unavoidably prevented from attending the meeting. Mr. F. B. George, who had been largely associated with the work, was also unable to be present.

Some time ago he had been able to arrange for Dr. Cromberg, a German author, to present to the Institute a paper which dealt chiefly with the time study of a wire mill. It had, however, always been difficult to gather from this and other published work information applicable to the industry as a whole. Some few years ago, he and

his then colleague, Mr. S. L. Poole, ventured to write a short article in the *Fuel Economy Review*. They suggested that, despite the variations in mill practice at one plant or even as between different plants, it would be possible to devise a method, by time studies, which would allow, more or less, of a standard of performance to be determined. Mr. F. B. George, of the Consett Iron Co., Ltd., having read that article, had been good enough to invite them to make a preliminary time study at the Consett works, and the major part of the investigation now reported on had resulted.

After briefly summarising the contents of the Report, Mr. Evans said that these time studies had made it possible to issue to the different shifts at one of the mills a standard pass specification for different sizes of ingots and different products. This was rigidly adhered to. With quite a small increase in the capital charges, the plant output was considerably increased. Further, essentially as a result of these studies it had proved possible to work one of the mills at something like a 10% greater output, in times of pressure, than had been possible previously. The results, he submitted, showed that such scientific studies, applied to individual mills, would assist in increasing plant efficiency.

Mr. T. W. HAND (Glasgow) said that, being a member of the Rolling Mill Committee, it would clearly be inappropriate for him to criticise the methods that had been adopted in developing the time studies reported on. He wished, however, to issue a note of warning against any feeling that it was intended to provide any complete solution of the disappointments experienced and the difficulties encountered in rolling-mill performance. There still remained the fundamental difficulty of establishing a standard time for any mill product. With that in mind, he would mention that in the mills operated by the company with which he was associated they were intending to fit pressure indicators under the screws of the mills in the hope of determining the actual rolling load. From that, they might proceed to develop uniform drafting, and when that had been established they would have gone some little distance towards the final creation of a standard time for any particular product.

Having reached that stage, it then remained to be seen whether rolling mills as at present constructed would stand up to a 100% load factor. Even in arriving at the position which they had so far reached, it had been necessary entirely to reconstruct many of their mills. Those were aspects which should be taken into account in attempting to apply these studies to any mill.

There was very little more that could be said. The Report told its own story, but, speaking on behalf of the Committee, he would like to say that if the publication of the studies did result in more intensive research and scientific management of rolling mills as generally understood, its immediate purpose would have been well served.

Mr. G. L. POTTER (London) said that the principal object of the time studies described in the Report had been to improve production by the scientific control of plant and operating processes. Essentially, the results of these production studies had been (1) to reveal defects or deficiencies in the services to the mill, such as heat, power and so on; (2) to determine the best draught reduction and pass specifications for rolling a particular product; and (3) to establish a common basis for comparing the results of widely varying outputs and types of product—in other words to give the mill manager a " yardstick " with which to measure mill performance.

There was, however, one problem which had not been solved by these studies, namely, the determination of the productive efficiency of the mill in comparison with its ideal efficiency. The actual performance of the mill as a machine had yet to be determined. This could not be done by the data already available, and in fact could not be done by time studies alone. Rolling mills, as far as could be seen, had been built very largely (in Britain) as the result of accumulated experience, and on the basis of that experience it was impossible, except by methods of trial and error, to determine the maximum output of the mill. During the period of high demand in the last few years, mills designed to roll specified quantities of product per week had frequently proved themselves capable of rolling a much greater amount, without material alteration to the mill itself, but of course with substantial improvements in the auxiliary services, such as power, soaking-pit capacity, and so on.

While it was a matter of considerable gratification to the rolling-mill manager to be able to increase his outputs in this way, the question did arise whether it was altogether a tribute to the mill designer that a plant should prove itself capable of an output considerably in excess of that for which it was designed. If a rolling mill was built to roll, say, 10,000 tons a week, and was proved to be capable of rolling, say, 18,000 tons, then that increase had only been possible because the factor of safety in the mill housings, bearings, and so on was considerably higher than was required by the iron and steel manufacturer when the contract was placed; and the question arose whether rolling-mill designers in Britain had the necessary data which would allow them to specify the ideal capacity of any mill constructed by them, thus giving to the mill manager a definite basis for determining mill performance by the comparison of the operating rates on a standard basis with the ideal capacity. In order that this might be done, far more measurement was required in rolling-mill operation than was available to-day. Roll-neck pressures, the power consumption per pass, the proportion of power utilised in the bearings, production studies, the effects of different types of manipulator gear, &c., on the output and quality of the product—these were all quantities which required to be measured if mill designers were to be given the data which they required. It was along these lines that his colleagues in the

Technical Department of the British Iron and Steel Federation and himself were working at the present time; and any assistance that engineers or others might be able to give in the investigation of this problem would be greatly appreciated.

Mr. H. C. Armstrong (Sheffield) remarked that, interesting as the results given in the Report were, its importance could not be gathered in a short time; there was so much in the Report that one was rather at a loss in taking part in the discussion, and perhaps it would be better if he were to confine himself principally to one point.

There was one special matter which had caught his eye and appealed to him very much, and which he did not think was altogether in the minds of the originators of the study reported on; but, as in many other things, once one got down to a very close and precise study, one found out many things which were bound to be of use. In Fig. 9 of the Report there was a curve giving the relationship between the net rolling time per ingot and the steam pressure. For many years he had been endeavouring to obtain a definite figure which would show the increase in the quantity of steam required to perform certain deformations. Perhaps he was more interested in the question of large and small forgings, and it was almost impossible to measure the amount of steam required to do unit work when forging under different pressures. The Report brought out very clearly the extra amount of steam required to perform certain work on rolling mills, which were probably analogous. It would be noticed from the curve in Fig. 9 that while the pressure dropped from 90 lb. to 60 lb. per sq. in., the net rolling time was doubled. That must mean that twice as much steam had to be used, as the losses past the piston rings, &c., were constant. It was perhaps rather a heavy pressure drop to decrease from 90 to 60 lb. per sq. in. Others might have mills working at higher pressure and decreases correspondingly as great, but, even if the steam pressure was not allowed to drop from 90 to 60 lb. per sq. in., the increased quantity of steam used over a day or over a week must be very great.

He thought that that was a very important matter, and it had a very great bearing on the question of steam accumulation, which was constantly being brought to one's attention. One of the claims of the steam accumulator was that constant pressure gave certain advantages. He would like to point out that the Report had definitely shown how great those advantages could be, and he thought that that was a very great step forward.

Mr. K. S. Lockie (London) said he would like to suggest the possible future use of time study for determining the maximum possible output of a mill. The first consideration was to reduce the number of passes used to a minimum. The principal requirement

for this was the use, for each pass, of the maximum safe draught reduction, provided that this did not require more than the maximum torque that could be obtained from the drive. The present system of draughting, which seemed to be fairly general, was to use a constant draught over certain ranges of thickness of material. For example, in the slabbing mill of Section C of the Report, constant reductions of about ½ in. were used for reducing the thickness of the slab ingot from 22 in. to about 12 in. If ½ in. draught could be used in the last passes, when the width of the slab had increased while the temperature and thickness had both decreased, it was certain that a considerably greater reduction could have been used in the early passes. The determination of maximum safe reductions involved the measurement of roll-neck pressures, speeds and driving torque for each pass, and so was rather outside the scope of a normal production study, unless made in co-operation with a research engineer.

There were, however, other requirements for determining the minimum possible number of passes. In many cases, a dummy pass was used at the completion of rolling, and, since this was pure waste time, it should be eliminated. Sometimes also immediately before a turn, a pass was taken with a very small reduction, this presumably being due to the fact that the mill team had no clear preconceived plan for the method of rolling. This stressed the value of the adoption of standard pass specifications and draughting.

The second consideration for obtaining the maximum mill output was the reduction of the rolling time irrespective of the number of passes. The manipulation time, which represented about 60% of the total time, was dependent on the equipment available and on the way in which it was operated, and it was here that time study, taken in great detail, could be used to indicate improvements. As an example, on a cogging mill rolling blooms more than about 60 ft. in length, it would appear to be advantageous to have two sets of manipulators—one of the tilting finger type to manipulate the ingot and one about 35 ft. from the rolls to grip and turn the long blooms. The maximum speed of transverse movement of the manipulators, consistent with the accurate centring of the ingot opposite the hole in the rolls, was also important, as was the designing of the rolls with the least possible distance between successive holes.

The rolling speed had a considerable effect on production, since if it was too high the ingot was thrown far out after each pass and the manipulation time increased, whilst if it was too low the net rolling time increased. There should be an optimum speed, at which the sum of the net rolling and manipulation times would be a minimum for each product. The rolling speed probably also had an effect on the number of ingots which stuck in the rolls, which seemed to be a fairly common cause of lost time.

All these factors were largely dependent on one another, and could not be regarded as separate problems. Their solution,

therefore, was most easily obtained by means of a detailed time and production study.

Mr. A. F. WEBBER (London) said he would like to qualify some of the definiteness of the conclusions which Mr. Armstrong had drawn from Fig. 9 in connection with steam consumption. It was very largely owing to an error of judgment on his own part that the steam consumption was not measured during the tests in question. The possibilities of putting in a steam meter had been considered, but it had then been his opinion that the steam pressure was so fluctuating that steam consumption tests would not have sufficient general interest. He now thought that he had been quite wrong, and that they would have been an exceedingly valuable part of the Report. That was past praying for now, however, and the curve shown in Fig. 9 only related the net rolling time to the steam pressure, and did not necessarily reflect the steam consumption directly. From Fig. 8 it would be seen that a good deal of the extra rolling time at low steam pressures occurred in the first few passes when the engine was unable to drag the ingot through the rolls at anything but a very slow speed. That meant that for most of the extra time the engine was running very slowly, and was therefore not consuming steam very fast. Moreover, at a pressure of 60 lb. per sq. in. each cylinderful of steam represented a considerably less weight than at 90 lb. per sq. in. pressure. There was little doubt that the steam consumption per ton of material rolled did increase with the fall in steam pressure, but he would be very chary of drawing quite so definite a conclusion as Mr. Armstrong appeared to have done, namely, that the steam consumption followed in direct proportion the curve of net rolling time against steam pressure.

Mr. E. P. HOLMES (London) remarked that it seemed to him that the Report had to a certain extent been prompted by the success of what he believed was known as the Bedaux system in other industries, *i.e.*, increasing the output by discovering wasted time. There seemed to him, however, to be a fundamental difference. As he understood it, the Bedaux system was chiefly applied to industries where the labour expenditure was far and away the chief expenditure of the industry. On the other hand, in the rolling mill the plant itself was quite probably the major partner of the two producing elements. It seemed to him that the Report failed in one respect with regard to that, namely, that it gave no real details of the plants in question. There had been some reference, for example, to Fig. 9, but nowhere in the Report was the size of that engine mentioned. The curve there seemed to indicate clearly that there was a minimum horse-power required on that particular mill, but there was no way of computing what that horse-power was. Further, for such things as manipulation and screwing-down there was no real information as to the actual power

as a force available. There was certainly the motor horse-power, but that meant nothing by itself, and he would suggest that it might be very useful if the Committee would supplement the Report by a more detailed description of the plant, if there was no objection to its disclosure, thereby making the Report as useful to the designer of rolling mills and to the engineers who had to put them down as it undoubtedly was to those who administered their later operation.

Mr. C. A. ABLETT (Kings Lynn, Norfolk) said that as a very old member of the Iron and Steel Institute he would like to recall a Carnegie Scholarship Memoir by Dr. Puppe,[1] which was printed about 1910, and which contained some very interesting information to those who were concerned with the subject under discussion.

He wished to refer to Fig. 7 of the Report. It would be seen in the table in that diagram that the net rolling time was about 100 sec., and the time taken by manipulation was about 150 sec.—a good deal more than the net rolling time. In the past, when he had been interested in the provision of speedy electrical plant for driving rolling mills, he had been very well aware of the time lost in the live roller gear. Recently three-phase electric current had come in, and he would suggest that live roller gear driven by three-phase motors was slower than that driven by direct-current motors. It would be interesting to see what support could be brought forward with regard to that point.

He happened to be interested in roller bearings as Chairman of a company manufacturing them. He did not want to take the attitude that "there was nothing like leather," but he did suggest that live roller gear fitted with roller bearings would start more quickly, be more easily handled, and would reduce the time of manipulation.

COMMITTEE'S REPLY.

In reply the COMMITTEE stated that the discussion had indicated several directions in which further work could be undertaken. The definition and measurement, for example, of the factors influencing the efficiency of rolling-mill operation in the mechanical sphere, would, in combination with more detailed time studies, supply a solution to some of the various points raised in the discussion. As an instance Mr. Hand mentioned that pressure indicators fitted under the screws would assist in providing a closer analysis of the factors affecting the variation in rolling times. The Technical Department of the British Iron and Steel Federation was considering this question with a view to specifying the most satisfactory type of instrument.

[1] *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1910, vol. 2, p. 271.

With regard to the comparative steam consumption when rolling at 60 lb. per sq. in. and at 90 lb. per sq. in., the length of the bloom in each pass could be calculated from the recorded draught reductions, using Tafel's and Sedlaczek's formula for spread. From these lengths and from the roll dimensions the total number of revolutions made by the engine during the actual deformation of the material could be determined.

In the case mentioned by Mr. Armstrong and taken from Table II. of the Report, the calculation showed that about 168 revolutions of the engine were required, both when the pressure was 60 lb. per sq. in. and 90 lb. per sq. in., in spite of the 6 extra passes used in the former case. Taking into account the difference in volume of a pound of steam at these different pressures, it seemed that the weight of steam used for reducing the ingot was actually less at the low steam pressure than at the high pressure in the ratio of 0·68 : 1·0. This did not take into account any variation in the cut-off position used.

Losses past the pistons, &c., were presumably greater at the 60 lb. per sq. in. than at the 90 lb. per sq. in. pressure, since the net rolling time was twice as great. Owing to the difference in the weight of steam per cubic foot, however, this could not be more than $2 \times 0{\cdot}68 = 1{\cdot}36$ times as great, even if the same volume of steam per minute were lost at the lower pressure. In addition to these factors, 6 extra reversals of the engine were necessary at the lower pressure. From these facts, therefore, it seemed probable that the steam consumption was very little, if at all, greater at 60 lb. per sq. in. than it was at 90 lb. per sq. in. pressure. This opinion was similar to that put forward by Mr. Webber.

With regard to Mr. Holmes' remarks, the Committee wished to point out that the investigation was primarily concerned with obtaining satisfactorily tonnage standards of performance to ensure control in planning, and not to determine basic wage rates depending upon the skill and speed of operators as in the Bedaux system.

Consideration was at present being given to power measurement, not only of the mill as a whole, but from pass to pass.

Mr. Ablett's remarks with respect to the influence of the type of bearings used in the roller racks would receive consideration.

FIFTH REPORT OF THE CORROSION COMMITTEE.

By a JOINT COMMITTEE of the Iron and Steel Institute and the British Iron and Steel Federation.

This Report is published as Special Report No. 21; it was presented at the Annual General Meeting of the Iron and Steel Institute, held in London, May 6, 1938.

Summary.

The Fifth Report of the Corrosion Committee is divided into six Sections. The first, Section A, is of an introductory nature and includes a summary of the conclusions so far reached by the Committee.

Section B, by J. C. Hudson, deals with the Committee's field tests on atmospheric corrosion. These tests, carried out on plain and low-alloy rolled irons and steels, have been in progress for 7 years in the case of the oldest specimens, and quantitative results for the corrosion of unpainted specimens exposed for periods of up to 5 years at several of the experimental stations are presented, together with the results of observations on painted specimens and stands. In the case of unpainted specimens exposed out of doors, the annual corrosion rate may be as high as 0·006 in. per year in highly polluted industrial atmospheres in Great Britain. In the tropics, despite unfavourable climatic conditions, the rate of corrosion is much less. The presence of copper in the steel reduces the rate of corrosion by as much as 30%, and that of small amounts of copper and chromium together by as much as 40%. In an atmosphere such as that of a railway tunnel the addition of copper to the steel has no appreciable effect, but such an addition does reduce the corrosion of steel railway sleepers in the open track. Tests on painted specimens have demonstrated that the surface treatment of the iron or steel before painting is of paramount importance. Paints have been observed to possess a considerably longer life on specimens descaled by pickling or sandblasting prior to painting, than on any other type of surface tested, including specimens with intact and unrusted rolling scale and others painted after exposure to the weather followed by hand-cleaning. The results of the tests on the painted stands show that the character of the priming coat is of importance; an increased life of the coating is obtained by the use of a priming coat of an inhibitive character.

Section C deals with marine corrosion and constitutes a continuation of previous studies by the Committee. Part 2 of this Section, by J. C. Hudson and T. A. Banfield, is devoted to a discussion on observations upon steel plates built into the barge *Cactus*, which, since the last inspection, had been in service for 2·2 years. The corrosion initiated by mechanical damage in service was considerable. Allowing for this, however, the condition of plates completely descaled by sandblasting or pickling was better than that of the weathered plates, whilst plates treated with white lead paint while still hot at the mill were in the best condition of all, except in the case of continuously submerged parts, on which marked flaking-off of the paint had occurred.

Section C, Part 3, also by J. C. Hudson and T. A. Banfield, deals with observations on plates built in H.M.S. *Basset*. Owing to the thorough maintenance of this class of vessel, including dry-docking and repainting at six-monthly intervals, no appreciable difference was apparent between plates subjected to different initial treatments, except that weathered plates were perhaps not so good as those pickled or given other special treatments.

Part 4 of Section C constitutes the report of a Panel set up to consider a case of abnormal corrosion observed on the underwater portions of H.M.S. *Niger*. The nature of the phenomena discussed is described in detail, and from the results of a series of comparative experiments the conclusion was reached that the heavy and rapid pitting of the shell plates of this vessel originated in the fact that the paint with which they were coated was damaged in launching and was probably aggravated by some form of electrical leakage which occurred while the vessel was afloat during the fitting-out period.

In Section C, Part 5, the results of inspections of three ships in which interesting cases of corrosion had occurred are described; in the cases of two of these vessels abnormal corrosion of the hull plates soon after launching had been arrested by zinc spraying and by careful cleaning and the application of gold size before re-painting.

Section D deals with laboratory corrosion tests. Part 2, by U. R. Evans, describes a method of transferring thin oxide films on metal to celluloid; the examination of such films is thereby facilitated, and the procedure constitutes a new and valuable method of research.

Part 3 of Section D describes a new electrical method of measuring the thickness of oxide films, which has been checked against optical and gravimetric methods. The results of work on the growth of oxide films on iron are summarised.

Parts 4 and 5 of this Section refer to the determination of the extent of the corrosion of wires by the decrease-in-breaking-load method; the results obtained after different periods of exposure in different localities are in satisfactory agreement with those of the

Committee's main tests on atmospheric corrosion by the loss-in-weight method.

Part 6 of Section D, by J. C. Hudson, records further observations on small painted specimens exposed at Birmingham and Farnborough. Earlier conclusions as to the effect of surface condition and the use of an inhibitive primer are substantiated.

The final Part of this Section, by J. C. Hudson and T. A. Banfield, details the results of experiments on the influence of various factors on the rate of dissolution of mild steel in sulphuric acid, these experiments being a preliminary to further tests on the effect of inhibitors.

The work of the Protective Coatings Sub-Committee is described in Part 1 of Section E, which concludes with a statement of their present views concerning the best procedure for painting iron and steel exposed to atmospheric corrosion; descaling is recommended, followed by the application of inhibitive priming coats, all painting being preferably carried out under dry conditions.

Part 2, Section E, reviews modern painting practice as revealed by the replies to questionnaires circulated by the Sub-Committee to various large users of structural steelwork. Considerable divergence in practice is revealed.

Part 3 of this Section deals with the surface preparation of steelwork prior to painting. Various methods of descaling are considered, together with the use of inhibitors or panel washes. An investigation of mechanical wire brushes made from several different types of steel is reported. Large-scale tests on a steelworks gantry demonstrated the advantage of pickling over hand-cleaning.

Section E, Part 4, by H. B. Footner, is devoted to a description of a pickling process involving descaling in sulphuric acid, washing in warm water and subsequent immersion in dilute phosphoric acid solution; this treatment is followed by shop painting with a good priming coat containing red lead. The pickling process is considerably cheaper than sandblasting and is applicable to the steel used for tanks, gas-holders and ships.

Part 5, by R. S. Thornhill and U. R. Evans, deals with experiments on the protection of steel by oxide coatings deposited from certain salt solutions; the method shows promise in preventing the seizure of screw threads and bolts.

In Part 6, Section E, H. Sutton and C. Braithwaite discuss experiments on the protection of steel by coatings other than paint. Of those tested, coatings of zinc, cadmium, nickel or aluminium gave the most favourable results.

The first Part of Section F summarises memoranda and other information submitted to the Committee, while Part 2 deals with four cases of corrosion reported to or investigated by the Committee. Mild-steel pipes and tubes buried in concrete were found to be perforated by corrosion due to an unsatisfactory concrete aggregate and bad drying conditions. The corrosion of wrought-iron rein-

forcement girders was traced to the presence of coke breeze in the aggregate. The two final cases concern the severe corrosion of some steel sleepers in a railway line near the sea and the rapid corrosion of ships' plates in Indian rivers, which was attributed to bacterial action.

Part 3 of Section F, by H. J. Bunker, deals with sulphate-reducing bacteria which may lead to the marked corrosion of iron and steel buried in the soil when oxygen is excluded.

The results of an examination of samples of the wrought iron and cast iron used in the construction of the Crystal Palace are dealt with in Part 4 of Section F.

The Report concludes with statements of corrosion researches in progress in countries other than Great Britain.

SECTION II.

A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.

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The Editor has been assisted in the preparation of this Survey by R. Elsdon, Librarian of the Institute.

REFRACTORY MATERIALS

The Situation with Regard to Raw Materials for the German Refractory Industry. F. Harders. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1127–1132). The possibilities of replacing imported raw materials for refractories by those of domestic origin are discussed. The highest grade quartzite for silica refractories is available only in limited amounts, but lower grades occur in sufficient quantity to cover requirements for some time. Germany's magnesite resources are limited, and so far no data are available as to the commercial success of various proposed methods for recovering it from dolomite or carnallite. For chromite Germany is entirely dependent on imported supplies. Graphite might be obtained from the deposits in Bavaria, but some would still have to be imported. Special refractories with silicon carbide or corundum bases can be obtained entirely from domestic raw materials; sillimanite refractories can be manufactured to a large extent from native minerals. Magnesium silicate refractories can be prepared from domestic raw materials, but alumina refractories cannot be satisfactorily prepared from German bauxite.

The Production of Chromite and Magnesite Refractories in Italy. L. Pompei. (Metallurgia Italiana, 1937, vol. 29, Aug., pp. 408–410). The author notes the absence of important deposits of chromite in Italy but examines at some length the deposits on the island of Rhodes. The magnesite deposits in Piedmont and Tuscany are discussed. The manufacture of refractories is briefly described.

Deformation and Young's Modulus of Fireclay Brick in Flexure at 1220° C. R. A. Heindl and W. L. Pendergast. (Journal of Research of the National Bureau of Standards, 1937, vol. 19, Sept., pp. 353–366). The authors have measured the plastic and elastic deformations of seventeen brands of fireclay brick. The bricks were primarily of the type intended for high-heat duty and included bricks made by the stiff-mud, dry-press, and hand-made methods of manufacture. Measurements were made at 1220° C. on eight brands as received from the manufacturers and on the seventeen brands after reheating at 1400° and 1500° C. Young's modulus of elasticity of specimens in flexure and the modulus of rupture of the bricks as received and also after heating at 1400° C. were determined at 1250° C. The results of the deformation tests show that size and quantity of aggregate, ratio of flux to silica, and temperature of preheating before test bear an important relation to the plastic and elastic deformation of these bricks. Young's modulus of elasticity at 1250° C. is only a small fraction of that at ordinary temperatures.

A Note on the Spalling of Fireclay Bricks. H. D. Bennie. (Transactions of the Ceramic Society, 1937, vol. 36, Sept., pp. 395–399). The author points out that the term " spalling " is used to cover a

number of different forms of disintegration in refractories. It is suggested that spalling is the breakdown of the structure of a refractory owing to the irregular mechanical strength of a brick or of a more or less solid mass of brickwork when subjected to thermal shock. Experimental work is described on fireclay bricks, to determine the effects of moderate-temperature spalling conditions.

Apparatus for the Determination of the Porosity of Firebricks by Gas Expansion. H. T. S. Swallow. (Transactions of the Ceramic Society, 1937, vol. 36, Sept., pp. 384–392). The author enumerates the advantages of the gas-expansion method as compared with the liquid absorption method for determining the porosity of firebricks; the former method is more rapid, more accurate, and can be applied to full-sized firebricks. The principle of the method, an apparatus designed for porosity determinations and the technique of using it are described in detail.

On the Thermal Conductivity of Ceramic Materials. B. Long. (Chaleur et Industrie, 1937, vol. 18, Aug., pp. 328–331). A mathematical treatment of problems in connection with the thermal conductivity of ceramics, including silica, alumina and vitreous refractories of various types.

The Grading of Coarse Refractory Aggregates. J. H. Chesters and L. Lee. (Transactions of the Ceramic Society, 1937, vol. 36, Sept., pp. 377–383). An account is given of some preliminary experimental results on the grading of coarse aggregates obtained by means of a machine of the type designed by Westman and Hugill. The report deals with the grading of mixtures of the following size groups: $\frac{1}{2}$ in.–$\frac{1}{4}$ in.; 7–25 mesh (B.S.I.); through 25 mesh. The mode of using the machine is described.

Practical Service Testing of Refractories for Alloy Steel Melting. E. E. Callinan and G. Soler. (Bulletin of the American Ceramic Society, 1937, vol. 16, Aug., pp. 329–334). The relation between the correct selection of refractories and the economics of steel-plant operation and steel qualities is indicated. The utilisation of laboratory tests and service tests in practice is emphasised. The effects of various factors found at the location of the service test and the requirements of these locations are all discussed. Examples of methods of carrying out tests in open-hearth and electric furnaces and in casting pits are given.

The Strength of Unburnt Ceramic Masses. H. von Wartenberg. (Angewandte Chemie, 1937, vol. 50, Sept. 4, pp. 734–737). When moistened with liquids, the grains of a powder are drawn together by the surface tension with a force which increases to thousands of atmospheres pressure as the distance between them decreases, and which operates uniformly throughout the mass, until they touch; then the molecular forces at the points of contact set up further cohesion, which increases with the number of points of contact. This number increases in the ratio of about $10 \times x^3$, when the size of the grains is decreased in the ratio of $1 : x$. Experiments on

slimed sand, $BaSO_4$, $CaCO_3$ and $BaCrO_4$ showed that the final strength of the dried shaped masses was as great as that produced by a measured mechanical pressure and increased greatly with a higher power of x. The sand, in various grain sizes, was moistened with water and with 96% alcohol. The strength rose rapidly with the degree of comminution, and the capillary attraction set up a final strength approximately the same as that produced by a mechanical pressure of 3000 kg. per sq. cm. The influence of the surface tension of different liquids on the final strength was noticeable only with grain sizes down to about 10 μ, in that a higher surface tension compressed the voids more. With liquids which did not " wet " completely, the surface tension set up flocculation (adhesion of the solid grains to one another) and reduced the strength.

Insulating Refractory Brick—Their Properties and Applications. A. V. Leun. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 274–292). The application of insulating refractory bricks to forge, reheating and heat-treatment furnaces will result in a large saving of fuel. Where slag attack or abrasion take place the use of fireclay brick is recommended, as insulating bricks are rapidly eroded and worn away. It is also recommended that all bricks be sprayed with a suitable high-temperature cement, and that care should be exercised to allow sufficient room for expansion in the walls. In the use of insulating bricks for suspended roofs, the suspension medium should be in the brick, as external suspension will cause early failure. In the operation of furnaces built of insulating brick far less actual heat input is necessary as compared with furnaces of fireclay brick. When cooling down, fireclay brick, having a high heat content, will allow for a slower furnace temperature drop than is the case with insulating brick. Where a slow temperature drop is desired, it is necessary to maintain a higher fuel input with insulating brick than with fireclay brick.

Methods of Testing Insulating Refractories. W. C. Rueckel. (Bulletin of the American Ceramic Society, 1937, vol. 16, Aug., pp. 319–321). The author discusses the tests usually applied to insulating refractories and concludes that the methods employed still require further investigation. Reheat-shrinkage, spalling, cold-crushing, transverse strength, hot-load strength, porosity, permeability, and thermal conductivity are dealt with.

FUEL

The Supply of Water to the Gutehoffnungshütte Works, Düsseldorf Division, with Particular Reference to Boiler Feed Water. R. Schruf and G. Ammer. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, Oct., pp. 185–205). The authors first describe the difficulties introduced by the passage of a hard ferruginous spring water through the supply mains and its use for cooling purposes in open-hearth and forge furnaces, and indicate the means adopted to overcome them. They then give details of the mode of treating the water, after removal of the iron, for cooling the furnaces and condensers and the oil-containing condensed water for feed-water purposes. Diagrams are presented to explain the process of softening and oil removal in an alkali phosphate plant, the de-aeration of the feed water by thermal means, and various parts of the plant. The costs of purifying the water supply are considered. Operating experience and results are recorded. In conclusion the authors give consideration to the supervision of the water supply, and describe the rapid methods and apparatus employed for the daily control of the supply.

Vaporisation of Boiler Salts. B. Koch. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, Oct., pp. 206–212). The author deals in detail with the question of the vaporisation of boiler salts in high-pressure boiler plants. Calculation of the partial vapour pressures at various temperatures of the quantities of salt and alkali present in boiler waters shows less than 0·00001 mg. per kg. of the salts can get into the steam from the vaporisation of the water. The amounts of salts found in the steam run to 2–3 mg. per kg. Hence the salt content of the steam is not due to vaporisation of salts but to moisture carried over, for, with a salt concentration in the boiler water of 2000 mg. per kg., only 0·1% of moisture in the steam will produce a salt content of 2 mg. per kg.

Fuel Economy in the Industry. A. F. Webber. (Iron and Steel Industry, 1937, vol. 10, Sept., pp. 591–594). The author discusses critically the present economic aspects of fuel consumption involved in the production of rolled steel from iron ore, and examines the changes which have occurred in the conception of the ideal economic situation as a result of the decreased quantity of fuel now required per ton of finished steel produced as compared with that required twenty years ago. He concludes that the idea of the " balanced works " is now no longer tenable.

The Exact Calculation of Heat Exchanges under Alternating Conditions. L. Thibaudier. (Revue de l'Industrie Minérale, 1937, No. 397, Mémoires, July 1–15, pp. 341–362). The author presents a method, based on the method of successive approximations, for calcu-

lating the heat exchanges under alternating conditions of temperature such as take place in air preheaters, of which the Cowper stove is typical. The mathematics of the problem are dealt with in detail.

The Ignition of Coal by Electric Current. H. Wöhlbier. (Glückauf, 1937, vol. 73, Sept. 11, pp. 852–855). This article, which is concerned with the investigation of the possibility of setting fire to coal by the passage of an electric current through it (a matter of importance in coal mines, in view of the numerous applications of electricity underground), contains an account of the author's determination of the electrical resistance of various bituminous coals, anthracite and fusain after storage for various periods in moist air.

The Correlation of Coal Seams by Microspore Content. A. Raistrick. (Colliery Engineering, 1937, vol. 14, Sept., pp. 299–302). The author describes, and briefly compares, methods of correlating coal seams by means of lithology, and by means of a study of fossil fauna and flora associated with the coal. The use of microspore and megaspore investigation is treated in greater detail, and the technique of the former is dealt with at length. The method is said to be both reliable and rapid.

Coal-Washing Plant at Smithywood Colliery. (Iron and Coal Trades Review, 1937, vol. 135, Sept. 10, pp. 397–399). An account is given of the coal-washing plant at the Smithywood Colliery of Messrs. Newton, Chambers and Co., Ltd. The plant operates on the Hoyois trough-washing system, which is briefly described.

Certain Improvements in Grading and Cleaning Plant. J. Venter. (Annales des Mines de Belgique, 1937, vol. 38, No. 2, pp. 359–362). Among the improvements effected in a coal-cleaning and grading plant at the Gosson-La Haye et Horloz mines at Tilleur, is the attachment of a drum-type magnetic separator for removing iron objects, particularly tools, from the coal before it is screened in order to minimise breakdown of the screening plant.

Works Control of Coal Cleaning at the Prosper Mine. G. Plessow. (Glückauf, 1937, vol. 73, Oct. 16, pp. 945–956). An account is given of the development of a system of control devised for the cleaning and grading plant at the Prosper Mine in the Arenberg Division of the Rheinische Stahlwerke A.-G.

The " Chance " Washer at Pemberton Colliery : Cleaning Large Unscreened Coal. (Colliery Guardian, 1937, vol. 155, Sept. 24, pp. 555–556). **Washing Run-of-Mine Coal.** (Colliery Engineering, 1937, vol. 14, Sept., pp. 303–308). An account is presented of the coal cleaner operating on the Chance sand-flotation system in use at Pemberton Colliery. The plant deals with about 1350 tons per day from a daily output of about 1750 tons.

Survey of the Development of the Coking of Coal in the last 10 Years. W. Reerink. (Glückauf, 1937, vol. 73, Sept. 4, pp. 813–824). The author first discusses generally the economic and technical development in the coking industry during the last ten years, and then reviews recent knowledge and improvements.

New Coking Installation on the North East Coast. The Cleveland Plant of Dorman, Long and Co., Ltd. (Iron and Steel Industry, 1937, vol. 10, Aug., pp. 555–559). (*See* Journ. I. and S.I., 1937, No. II., p. 167 A).

The Coal Research Laboratory of the Carnegie Institute of Technology. H. H. Lowry. (Journal of the Institute of Fuel, 1937, vol. 10, June, pp. 291–301). The investigations carried out at the Coal Research Laboratory of the Carnegie Institute of Technology, Pittsburgh, U.S.A., on the mechanism of the thermal decomposition of coal, are described. The chemical and physical aspects of the problems involved are discussed.

Internal Evacuation during Coking and a New Way of Doing it. H. Niggemann. (Glückauf, 1937, vol. 73, July 31, pp. 705–710). After an introductory reference to the low-temperature carbonisation of coal, the author shows that during the coking of coal each particle undergoes low-temperature carbonisation as an intermediate stage, and that it is of great importance to recover the volatile products then generated before they decompose further, because this combination of low-temperature carbonisation and coking promises a sure way of increasing greatly the oil yield during coking, and the heavy oils recoverable in this way can be easily converted into motor fuels by hydrogenation. After a brief description of previous proposed methods of internal evacuation, the author describes his own method of evacuation through the oven doors which has been in large-scale operation for some time. Three coke-oven batteries, each of 45 ovens, were rearranged suitably, and yield daily 8 tons of a high-grade heavy oil; further ovens are being converted to the new process. The influence of the internal evacuation on the oil yield in practice being uncertain, comparative tests with and without internal evacuation were made; it was found that the oil yield increased by 40% in 4 m. high ovens and by 21% in 2·4 m. high ovens.

Control of Expansion in Modern Coke Ovens. C. Berthelot. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Oct., pp. 153–155). The author considers the use of silica and semi-silica refractories in the construction of coke-ovens, with special reference to plant recently put into commission by the Hardwick By-Product Co., Ltd. Structural details of devices to control expansion are discussed at some length.

Low-Temperature Carbonisation at Bolsover. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Oct., pp. 156–162, 165). A description is given of the Coalite plant recently installed by Low-Temperature Carbonisation, Ltd., at their Bolsover works. The plant, which is situated immediately adjacent to Bolsover Colliery, is capable of carbonising 750 tons of coal per day. The by-product plant comprises electrostatic precipitators, catchment vessels, and ammonia scrubbers. The plant yields 18 gal. of oil and 5 lb. of ammonium sulphate per ton of coal carbonised; about 15 cwt. of Coalite are produced simultaneously.

Tar Recovery with Tube Stills. H. Reisner. (Zeitschrift des Österreichischen Ingenieur- und Architekten-Vereines, 1937, vol. 89, Sept. 17, pp. 257–258). A brief note on the continuous distillation of tar in tube stills.

Condensation Cleaning of Blast-Furnace Gas. R. R. Harmon. (Steel, 1937, vol. 101, Aug. 23, pp. 62–65, 76). The author discusses a new condensation method of cleaning blast-furnace gas. The physical bases of the method are examined, the procedure is described in detail and the results obtained are critically considered. Graphical data are presented.

The Drying of Gases by Calcium Chloride. The Solvay Company. (Chimie et Industrie, 1937, vol. 38, July, pp. 3–12). The design and operation of calcium chloride gas drying plants are examined, and the physical and chemical bases governing their use in practice are discussed.

The Drying of Gases by Calcium Chloride. The Solvay Company. (Gas World, 1937, vol. 107, Sept. 4, pp. 197–201). A slightly abridged translation of the article referred to in the previous abstract.

On Naphthalene Removal from Coke-Oven Gas Mains at Rutchenkovo Stalins. A. Stchukin. (Stal, 1936, No. 8, pp. 81–88; No. 9, pp. 57–65). (In Russian).

The Katasulph Process. H. Bähr. (Glückauf, 1937, vol. 73, Oct. 2, pp. 901–913). The development, theory and practical application of the method for freeing coke-oven gas from ammonia and hydrogen sulphide by the catalytic oxidation of the latter in the presence of the former to give ammonium sulphite, acid sulphite and thiosulphate (which are subsequently removed by washing) are described.

The Use of Active Materials in the Coke and Gas Industries. A. Engelhardt. (Glückauf, 1937, vol. 73, Oct. 9, pp. 925–933). The author describes briefly the theory of adsorption, and then discusses in detail the use of active carbon for drying and desulphurising gases and for recovering special constituents from coke-oven gas.

PRODUCTION OF IRON

Determination of the Dimensions of Blast-Furnaces. M. A. Pavloff. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Mar., pp. 215–224; Apr., pp. 264–275; May, pp. 327–338; June, pp. 383–396; July, pp. 423–428). The author traces the history of the development of the lines of the blast-furnace in various countries. In the first part he deals with very early coke furnaces, and with the lives of charcoal furnaces, making considerable reference to Russian furnaces, and in the second part he surveys the development of the coke blast-furnace in numerous lands. The third part covers the determination of the dimensions of the blast-furnace, its height under different conditions, its capacity and other essential measurements, the dimensions of representative plants being cited. Parts four and five deal with dimensions of various parts of the blast-furnace, and methods of calculating these for any given conditions.

Steel Recuperator for Blast-Furnaces. O. Johannsen and A. Holschuh. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1142–1143). The authors describe the structure and performance of the steel recuperator at the Röchling Iron and Steel Works, Völklingen. It is attached to a blast-furnace with a daily output of 400–500 tons of basic pig from Minette ore and sinter. Tabular data are given in which the normal hot-blast stove is compared with the recuperator.

Oxygen as an Aid in Metallurgical Processes. R. Durrer. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1118–1119). The author briefly discusses the low cost of oxygen and indicates that the use of oxygen-enriched air in blast-furnace practice results in decreased coke consumption, higher outputs, and higher working temperatures (which are of great importance in the smelting of acid ores). With greater additions of oxygen, preheating of the blast becomes unnecessary; the height of the blast-furnace may then be reduced and in appearance and operation it approaches the electric furnace.

Acid Smelting in the Blast-Furnace and the Significance of Alkaline Slags in the Metallurgical Processes. M. Paschke. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1114–1117). The acid smelting of silica-rich low-grade iron ores, followed by soda-desulphurising, enables various grades of pig iron to be produced. The slag produced in the manufacture of manganiferous pig iron (Stahleisen) forms a valuable constituent in the blast-furnace burden for ferro-manganese manufacture. Further suggestions are made concerning economy in manganese, the use of coke from low-grade coal, the working up of titaniferous ores, and the use of low-grade bauxite in conjunction with soda to produce a slag which will give an easily soluble alumina for the production of aluminium. The sintering of refractory alumina with additions of lime and soda, and the use of slag residues for cement are dealt with.

Desulphurisation of Pig Iron and Steel. T. P. Colclough. (Foundry Trade Journal, 1937, vol. 57, Sept. 9, pp. 201–202, 204: Iron and Coal Trades Review, 1937, vol. 135, Sept. 3, pp. 362–364). After referring to the recently developed method of acid burdening of blast-furnaces in order to attain maximum outputs of iron with minimum coke consumption, the author points out that the sulphur content of the iron as tapped is ignored, any excess being removed by subsequent treatment; this is carried out by treatment with sodium carbonate in the ladle. The chemistry of desulphurisation in this way is discussed, and the mixtures employed and results obtained are examined. The desulphurisation of pig iron for steel-making is also discussed.

The Significance of Power Economy for the Type and Site of German Iron-Ore Smelting. K. Rummel. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1097–1103). The author discusses the fundamental requirements for an efficient organisation of the smelting of German iron ores. The difficulties of disposing of large quantities of excess blast-furnace gas are discussed, and means of reducing the excess by controlled pretreatment of the blast-furnace charge and by control of the constituents forming the charge are described. The utilisation of energy produced in pretreatment processes is also referred to.

Composition of Pig Iron Collected from Flush Slag. T. L. Joseph. (Blast Furnace and Steel Plant, 1937, vol. 25, July, pp. 716–718). The author investigates the silicon, sulphur and manganese contents of metal collected from the cinder-runner of a blast-furnace. The mechanism of the increase in the silicon and manganese contents of such metal is discussed, and is shown to be due to reactions in the crucible. The decreased sulphur content is attributed to the finely divided state of the metal in the slag.

Electric Pig Iron. F. Giolitti. (Metal Progress, 1937, vol. 32, Sept., pp. 268–269). The author describes the construction and operation of the Tysland-Hole electric furnace for the production of pig iron. The high quality of the gases produced and the possibility of their wide industrial use are stressed, and particular reference is made to the possibility of employing low-grade cokes and anthracites. The low installation and maintenance costs are noted, and the power consumption is stated to vary from 2100 to 2750 kWh. per ton of iron produced. Plants in Norway, Italy, Sweden and Finland are mentioned; in the last-named country a 12000-kVA. unit has recently been constructed. Figures are presented regarding the analyses of irons obtained from Italian furnaces smelting calcined pyrites.

The Raw-Material Situation and the Problem of Manganese in Pig-Iron Production. H. Bansen. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1109–1114). The author discusses the types of ores employed and the most satisfactory methods for producing pig iron for steel manufacture. The fundamental reasons for manganese

losses in present-day practice and the necessity for evolving a means of ensuring the most complete recirculation of this element are discussed; the use of three specific types of pig iron is indicated in this regard. Among the methods for manganese recovery, that of Löfquist is described; the slag produced is employed for working up into ferro-manganese. Other elements occurring in the raw material and the finished pig iron, such as copper, titanium, nickel, chromium, vanadium and arsenic are also discussed.

The Raw-Material Situation and Problems in the Grading of Pig Iron and Steel. P. Reichardt. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1104–1109). The author discusses the changes which have taken place in the German iron and steel industry since pre-war days, in the consumption of pig iron and scrap, and in the relative outputs of basic and acid open-hearth steels. It is demonstrated from flow-sheets that the circulation of scrap follows a determined route and that the quantities available increase with an increasing output of steel. It is to be anticipated that by the utilisation of German phosphoric ores the increase in scrap and old metal will amount to 53% of the iron content of these ores, hence a broader basis will be laid for the production of steel by the acid open-hearth process. A ton of iron in the form of ore will yield 1·5 tons of raw steel, one third of which will be acid open-hearth grade; in finished work, however, the yield will be about 0·7 ton of basic and 0·33 ton of acid steel. The substitution of a considerable quantity of low-phosphorus ore in present basic open-hearth practice by domestic ores high in phosphorus, will release the low-phosphorus material for further use.

Since the phosphorus content of domestic ores is not in every case high enough to provide a satisfactory basic pig, either phosphorus must be added to the blast-furnace charge or basic slag must be worked up to supply the deficiency; the relative advantages of each method are discussed. The utilisation of acid open-hearth slag in the blast-furnace is also discussed.

FOUNDRY PRACTICE

Management, Production Control and Testing of Materials in a Large German Foundry, with Special Reference to the Four Years Plan. E. Pohl. (Giesserei, 1937, vol. 24, Sept. 10, pp. 461–468; Sept. 24, pp. 488–490). The author describes the control systems applied in technical departments and to production in a large German foundry. Systematic investigation of materials and the development of cast irons are also dealt with.

Designing Castings to Develop Strength Properties. L. F. C. Girardet. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Sept. 16, p. 234). The author shows that the design of castings intended to possess favourable strength properties cannot be based exclusively on the results of static tests. The metallographic characteristics of a cast material and the fundamental mechanical characteristics of the design must each be taken into account. The design should be such that in casting, ideal or approximations to ideal conditions obtain in the finished work with respect to the purpose for which it is to be used.

On the Question of Dimensional Variations in Foundry Products. O. Hengstenberg. (Technische Mitteilungen Krupp, 1937, vol. 5, Oct., pp. 221–225). The author concludes that no tolerance standards of general applicability are possible for cast components, but that in repetition work a limited control is possible by means of statistical investigations.

Operation of a 24-inch Cupola. F. A. Andrew. (Institute of British Foundrymen : Foundry Trade Journal, 1937, vol. 57, Oct. 28, pp. 337–338). The author describes in detail the preparing of the cupola, the charging and the blowing-in operation with regard to a small cupola. The calculation of mixtures (for which a special graph is presented) is dealt with at length, and the subject of blast pressure is also discussed in detail.

Cast Iron as Affected by Coke Size in Cupola Melting. J. A. Bowers and J. T. Mackenzie. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 293–324). In an effort to secure more definite information as to the effect of coke size on the melting of iron and its influence on the physical properties of the castings, the authors ran a series of tests in a 21-in. cupola, using four sizes of coke ranging from 1 to 4 in. Details of the tests are reported, including a complete record of each heat and the chemical and physical data on the iron from each ladle. The results are presented in a series of charts, which show the fluctuation of sulphur, silicon, manganese and carbon, the temperature changes and trends in physical properties. While the authors state that the results are considered to be applicable to 21-in. cupola operation only, they are of interest from their possible application to general cupola melting. The authors

conclude that for heats of comparatively short duration the sulphur and carbon pick-up increases and the silicon and manganese losses decrease with each decrease in coke size. For heats of longer duration the changes in the elements are practically unaffected by changes in the coke size after the first eight or ten ladles.

Self-Fluxing Foundry Coke. G. Hénon. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Sept. 30, p. 267). The author describes experiments on a coke blended in such a manner that the resultant ash would require no flux addition to give a normal slag in the cupola. Analyses of slags and coke ash are discussed, and the method of blending which is derived from these figures is detailed. Foundry tests on the self-fluxing coke demonstrated that the refractory wear in the cupola was diminished, that low-carbon charges underwent less recarburisation, and that the sulphur pick-up was increased by an insignificant amount which could be decreased by soda-ash treatment if required.

Refining Iron in Mixing Ladles. G. S. Evans. (American Foundrymen's Association : Foundry, 1937, vol. 65, Aug., pp. 26–27, 72, 74). The author discusses the mechanism of the refining action of soda ash in the cupola, to which it may be added with the limestone at the rate of 2 to 4 lb. per ton of metal. Combustion is improved and entrapped oxide-silicate inclusions are fluxed out. The advantages of refining in a mixer ladle or forehearth equipment are dealt with at length, the technique being fully explained and some typical mixtures discussed.

The Melting of Grey Cast Iron in Different Types of Furnaces. S. E. Dawson. (Metallurgia, 1937, vol. 16, July, pp. 81–82; Aug., pp. 119–121). Various factors which influence the character and properties of cast iron are briefly discussed with particular reference to the method of melting employed. Various types of melting furnaces are compared, and some indications of relative melting charges given. Attention is specially directed to the rotary type of furnace and the cupola, and also to crucibles.

Developments in Melting Malleable Cast Iron. W. R. Bean. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 334–342). The author outlines recent developments in the melting of malleable cast iron with special reference to duplexing and the use of pulverised coal.

Sand Control in Relation to Steel Foundry Problems. C. Fuerst. (Transactions of the American Foundrymen's Association, 1937, vol. 45, pp. 325–333). The author shows in a practical way, the value and need of accurate sand control in the production of sound steel castings.

Sandslinger with Separator for Iron. U. Lohse. (Giesserei, 1937, vol. 24, Oct. 8, pp. 518–519). A description is given of a recently developed sandslinger in which is incorporated a magnetic separator for removing particles of iron from the used sand before it is mixed with raw sand and used in the machine.

Saving Metal by Compound-Casting. E. Knipp. (Giesserei, 1937, vol. 24, Sept. 24, pp. 485–487). The advantages, technique and practical application of the casting of iron on to non-ferrous alloy components in order to confer strength and to economise in the latter materials are described.

Plant and Production Methods of Triplex Foundry Limited, Tipton. (Foundry Trade Journal, 1937, vol. 57, Oct. 28, pp. 333–339). Details are given of the plant and plant layout at the Triplex Foundry. The melting and casting shops are described and particular reference is made to fettling and cleaning and to the cycle of operations involved in preparing the castings for vitreous enamelling.

Defects in Difficult Castings. J. L. Francis. (Iron and Steel Industry, 1937, vol. 10, Sept., pp. 598–602). The author discusses the conditions for minimum shrinkage defects in castings and examines the operation and use of risers and feeding heads. The use of denseners and inserts is discussed. The design of castings is examined in some detail and certain difficult examples are discussed, and means of avoiding probable defects in the finished casting are noted. The influence of pouring speed and temperature is referred to.

The Apparent-Density Test-Piece. C. Dennery. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Sept. 30, pp. 270, 272). The author explains the significance of the apparent-density test-piece, discusses the shape, size and casting procedure required for making the test-piece, outlines preliminary studies on relation between pouring temperature and pressure tightness, and details complementary tests. The application of the procedure described refers specifically to brass-foundry work.

Studies of Casting Stresses in Chilled Iron Rolls. J. Erler. (International Foundry Congress, Düsseldorf, 1936 : Iron Age, 1937, vol. 140, Aug. 26, pp. 46–51, 81). The author discusses the origin of abnormal casting stresses in rolls which may lead to failure at relatively low loads. The origin of casting and cooling stresses are examined and the results of investigations of these phenomena are correlated with the fundamental elastic properties of the metal.

PRODUCTION OF STEEL

Visits to Works. (Iron and Coal Trades Review, 1937, vol. 135, Sept. 17, pp. 442–458). Accounts are presented of the plant and layout at the following works: Tees-Side Bridge and Engineering Works, Ltd.; The Cleveland Bridge and Engineering Co., Ltd.; The Ormesby Ironworks of Cochrane's (Middlesbro') Foundry, Ltd.; Head, Wrightson and Co., Ltd.; Whessoe Foundry and Engineering Co., Ltd.; Darlington Rolling Mills Co., Ltd.; Ashmore, Benson, Pease and Co., Ltd.; The Darlington Forge Co., Ltd.; the iron and steel works of the Skinningrove Iron Co., Ltd.; the Billingham factory of Imperial Chemical Industries, Ltd.

Gary, Steel's Greatest Achievement. C. Longenecker. (Blast Furnace and Steel Plant, 1937, vol. 25, Aug., pp. 873–918). After an historical account of the Gary Works of the Carnegie-Illinois Steel Corporation, a detailed account is presented of the plant, plant layout and production of the works. Power production equipment and auxiliary sections are also dealt with. The account includes a plan of the entire works showing the interconnections between departments.

Perrin's Rapid Steel Refining. R. Perrin. (Iron Age, 1937, vol. 140, Oct. 14, pp. 123–148). The author describes the development, theory and practice of the Ugine-Perrin processes as applied to the dephosphorisation and deoxidation of basic Bessemer steel and operated at plant owned by the Société d'Electro-Chimie, d'Electro-Métallurgie et des Aciéries Electriques d'Ugine. Molten basic steel is refined by suitable treatment with molten acid slag; the satisfactory treatment of acid Bessemer steel is also said to be quite possible. The process is extremely rapid. The physical and chemical aspects of the process are examined in some detail, and tabular data are presented with regard to the mechanical properties of some nickel-chromium steels containing approximately 2·8% of nickel, 0·75% of chromium and 0·36% of carbon, manufactured by the process.

A Modern 300-ton Tilting Furnace. (Iron and Steel Industry, 1937, vol. 10, Sept., pp. 607–609). An account is presented of the construction of the 300-ton tilting furnace recently installed in the melting shop of the Appleby Works of the Appleby-Frodingham Steel Co., Ltd. The bath of the furnace is 45 ft. long by 15 ft. wide inside the refractories, giving a hearth area of 675 sq. ft. The furnace is fired by producer gas, but the valve system is so arranged that mixed-gas firing can be used.

Steel Company of Canada's Furnace Automatically Controlled. C. Longenecker. (Blast Furnace and Steel Plant, 1937, vol. 25, July, pp. 705–708). The construction and operation of a 150-ton open-hearth furnace recently installed by the Steel Company of

Canada at Hamilton, Ontario, Canada, are described. This plant is largely automatic, and the system of controls is discussed in some detail.

The Manufacture of Steel in the Open-Hearth Starting from Solid Charges. Succinct Comparison with Manufacture in the Electric Arc Furnace. J. Thomas. (Mémorial de l'Artillerie Française, 1937, vol. 16, pp. 251–269). The author first discusses the reactions taking place during the refining of steel in the open-hearth furnace, and then gives some information concerning the working of the charge. Finally, he gives a short comparison of the chemical reactions occurring in the open-hearth with those in the electric arc furnace.

Quality of Seamless Tubes Made from High-Arsenic Steel. D. Ludogovsky. (Stal, 1936, No. 8, pp. 64–70; No. 10, pp. 57–68). The author describes trial heats of basic steel made from Kertch ores containing 0·78–0·21% of arsenic. (In Russian).

Modern Methods of Steel Production. G. C. Castle. (Electrical Engineer, 1937, vol. 4, Sept. 24, pp. 848–849). The author describes briefly the evolution of the modern electric furnace and then proceeds to discuss the production of pure iron by the electric melting of sponge iron, which is manufactured by reducing the ores at temperatures about 300° C. below the melting point and effecting a partial separation from the gangue by liquation. The production of calcium carbide is also dealt with.

Concerning the Early Working of Steel. (Metallwirtschaft, 1937, vol. 16, Oct. 8, pp. 1041–1042). A review is given of early documentary evidence bearing on the manufacture, hardening and working of steel. Early Greek, Egyptian, Indian, Italian, African, Chinese and Japanese sources are examined.

ROLLING-MILL PRACTICE

The Importance of the Rolling Mill in Establishing Operating Conditions and Costs in Iron and Steel Works. A. Nöll. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1120–1125). The author discusses the value of production research for the appraisal and development of the efficiency of a works. The importance of the rolling mill in regard to equipment and production costs is compared to that of other sections of the works. The progressive development of the rolling mill is described; first deficiencies in old plant were made good, then later modern plant was laid down for heavy continuous outputs. Particular reference is made to rod and bar production.

Hot-Rolling Experiments on Straight-Carbon and High-Alloy Steels. (Metal Treatment, 1937, vol. 3, Autumn issue, pp. 143–148, 154). An abridged English translation of an article by G. Weddige the original of which appeared in Stahl und Eisen, 1937, vol. 57, Aug. 19, pp. 913–920. (*See* Journ. I. and S.I., 1937, No. II., p. 225 A).

Laminated Bearings Give Good Service on Tool Steel Mill Pinion Plant. V. E. Enz. (Steel, 1937, vol. 101, Sept. 20, pp. 64, 67). A description is given of the fitting of Micarta lined water-cooled and water-lubricated bearings to a rolling mill. The service rendered by such bearings is compared with that given by white-metal bearings, but the nature of the lining is not discussed.

H. Vollet's Machine for Mechanical Tests on Lubricants and Various Antifrictional Metals. J. Prévost. (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1937, vol. 136, May–June, pp. 247–266). The author first gives an illustrated description of the Vollet machine for testing lubricants, followed by a mathematical study of the apparatus, and then presents the results of a number of experimental tests made on various materials and carried out with this machine.

High Quality Wire from New Joliet Mill. (Blast Furnace and Steel Plant, 1937, vol. 25, July, pp. 719–722). The continuous rod rolling mill in operation at the Joliet plant of the American Steel and Wire Co. is described. (*See also* Journ. I. and S.I., 1937, No. II., p. 183 A).

Coefficient of Friction and Flow in Strip Rolling. W. Trinks. (Blast Furnace and Steel Plant, 1937, vol. 25, July, pp. 713–715). The author briefly notes a method of obtaining the coefficient of friction between hot steel and smooth cold steel, and discusses the results of previous investigations by other workers. The coefficient of friction and flow resistance are then examined mathematically in regard to hot and cold strip rolling. Data are presented in graphical form.

HEAT TREATMENT

Continuous Gas Carburizing of Automotive Ring Gears. R. W. Roush. (Steel, 1937, vol. 101, Aug. 23, pp. 38–41). A description is given of a 38-ft. carburising furnace installed at the Detroit Works of the Timken-Detroit Axle Co., by the Surface Combustion Corp., Toledo, Ohio. The furnace is equipped with an arched muffle 26 ft. long, 31 in. wide and 12 in. in effective height. The muffle is constructed of 8 sections of alloy steel, $\frac{1}{2}$ in. in thickness, joined by welding. Special provision is made for thermal expansion. Under- and over-fired high-pressure gas heating is employed, and the carburising gas is admitted at six ports—one at the charging end and five along the top of the muffle. The carburising gas consists of cracked natural gas prepared in a special plant; analyses are given for the gas before and after cracking. Operating data are presented, including temperatures, charges, methods of quenching, and the type of case produced.

Continuous Carburizing by Gas. A. J. G. Smith. (Gas Journal, 1937, vol. 219, Aug. 18, p. 413). A rotary furnace fired with either a mixture of natural gas and coal gas, or coal gas enriched with small amounts of benzol, is described. The furnace was constructed by the American Gas Furnace Co., Elizabeth, and is employed for carburising self-tapping screws to a depth of about 0·0075 in. Output figures are discussed.

Surface Hardening with the Oxy-Acetylene Flame. A. K. Seemann. (Metal Progress, 1937, vol. 32, Sept., pp. 247–251). The author describes the theory and practice of flame-hardening. Reference is made to the adaptation of the oxygen cutting machine for flame-hardening purposes.

X-Ray and Microscopic Studies on the Nitrided Layer in Nitriding Steels. G. Hägg. (Ingeniörsvetenskapsakademien, 1937, Handlingar, No. 143). This paper, which was previously published in Jernkontorets Annaler, 1937, vol. 121, pp. 199–217, has now been published in English. (*See* Journ. I. and S.I., 1937, No. II., p. 187 A).

New Plant, New Equipment for Steel-Treating Firm. W. C. Kernahan. (Heat Treating and Forging, 1937, vol. 23, Aug., pp. 377–379). A description is given of the plant layout at the new works of the Queen City Steel Treating Co., Cincinnati, Ohio. Of the seven departments forming the works, the large-furnace and pot-furnace departments and the automatic furnace department are noted; the second is for cyanide-hardening work. A special copper-brazing department is also described in detail; it is provided with a 45-kW. mesh-belt conveyor electric furnace constructed by the General Electric Co.

Air-Jacketed Heat Treatment and Forging Furnaces. D. Brownlie. (Iron and Steel Industry, 1937, vol. 10, Aug., pp. 587–588). The author describes the air-jacketed type of heat-treatment and forging furnaces introduced by Liptak Furnace Arches, Ltd. The new design is compared to the older and more conventional furnace types. Economy in fuel is claimed for the new design.

Bethlehem Expands Electric Heat-Treating Facilities. S. D. Gladding. (Heat Treating and Forging, 1937, vol. 23, Aug., pp. 401–403). An account is given of new plant installed by the Bethlehem Steel Co. at its Bethlehem Works. This plant includes an electrically heated preheating oven and four bell-type car-bottom furnaces. An increased output from the heat-treatment shop of about 840 tons per month is anticipated. The account includes structural details of the new equipment and a description of the layout of the heat-treating department.

Heat Treatment of Large Nickel-Chromium Steel Castings. J. Obrebski. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Sept. 2, pp. 173–174). The author describes the general conditions governing the heat treatment of nickel-chromium steel castings weighing more than a ton. Preliminary laboratory experiments on a basic open-hearth steel containing 0·30% of carbon, 3·52% of nickel, 0·89% of chromium, 0·70% of manganese, 0·34% of silicon, 0·02% of sulphur, and 0·015% of phosphorus, are described. From these experiments, general conclusions as to heat treatments are derived. Tabular and graphical data are presented.

Improving Chilled Car Wheels. S. C. Masari. (Steel, 1937, vol. 101, Aug. 23, pp. 42–43, 69). A heat-treatment cycle is described for improving the quality of chilled-iron car wheels, whereby internal casting stresses are relieved and the as-cast structure is modified in such a way that its impact strength is increased and its resistance to thermal shock improved. A specially designed furnace is described in which the rate of heating and cooling of the castings is automatically controlled.

Heat Treatment of Grey Cast Iron by Quenching and Tempering. A. B. Everest. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 70–74). The author discusses the effects of heat treatment on nickel and nickel-chromium grey irons, and the relationship between the composition, treatment and properties. Some typical applications of hardened and tempered cast irons are discussed.

On the Deformation Accompanying the Heat Treatment of Cold-Worked Components. M. Bonzel. (Revue de Métallurgie, Mémoires, 1937, vol. 34, June, pp. 372–382; July, pp. 429–439). Consequent upon heat treatment, cold-worked products are often found to have suffered considerable distortion. To investigate this phenomenon in the case of automobile valve springs, the author studied the distortion of various test-pieces, including carbon steels, nickel-chromium steels, manganese steel and high nickel-chromium steel,

subjected to cold bending and torsion and subsequently heated. Special autographic apparatus is described for determining the distortion process. Dilatometric anomalies consequent upon the disturbance of quasi-isotropic conditions by cold-working are discussed, and the cold- and hot-working processes are compared. Certain anomalies were observed in the Ar and Ac temperatures. The results of bend tests are analysed, and the practical applications of the data obtained in the investigations as a whole are examined.

192-kW. Electric Annealing Furnace. (Engineering, 1937, vol. 144, Aug. 27, p. 244). An account is presented of a double-ended roller-heater type electric annealing furnace, operated on 3-phase, 50-cycle, 440-volt current stepped down by transformers mounted on top of the furnace. A full account is given of the construction of the furnace.

The Grünewald Bright-Annealing Process. S. V. Williams. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 55–59). The author describes the construction and mode of operation of the Grünewald bright-annealing furnace in which, it is noted, the use of a controlled atmosphere was originally rendered unnecessary, although in the modified process provision is made for introducing an artificial atmosphere into the pot. The difficulties caused by the presence of residual rolling or drawing lubricants on the charge are discussed at some length, and the value of the modified process referred to above is examined in connection with the overcoming of these difficulties. The production of, the mode of employing, and the advantages of an artificial atmosphere are considered, and the application of the process to mild and low-carbon steels, medium and high-carbon steels and tinplate is discussed.

Conveyor-Type, Scale-Free Hardening Furnaces. A. R. Ryan. (Iron Age, 1937, vol. 140, Sept. 2, pp. 46–49). A general account of the construction and working of a conveyor-type controlled-atmosphere electric heat-treatment furnace is presented. Its use for the treatment of small components produced on high-production machinery is specifically referred to. The controlled atmosphere is provided by processed coke-oven gas, natural gas, butane or propane.

Controlled Hardening of Tools. F. M. Reiter, L. L. Grenell and E. C. Adkins. (Metal Progress, 1937, vol. 32, Sept., pp. 240–246). The article is divided into three sections. The first, by Reiter, deals with the problems associated with chemical reactions occurring between the heated furnace charge and the furnace atmosphere, and with the means of controlling the resultant attack on the steel. The second, by Grenell, deals with the influence of the composition of the steel on that of the atmosphere required to produce optimum results. The third section, by Adkins, deals with the choice of a suitable furnace for hardening tool steels and with atmosphere control.

WELDING AND CUTTING

A New Technique in the Production and Utilisation of the Oxygen-Acetylene Mixture. R. Magloire. (Chaleur et Industrie, 1937, vol. 18, Aug., pp. 345–347). An account is presented of the "Volcan" acetylene generator, which is claimed to produce very economically and safely high-purity acetylene for welding purposes. The relative merits of the Volcan plant and of the dissolved-acetylene system are compared.

Resistance Welding Improved by Thyratron Control. W. C. Hutchins. (General Electric Review: Welding Journal, 1937, vol. 16, Aug., pp. 11–18). The author describes various types of mechanical control for spot and seam welding machines, points out their limitations, and examines in detail the advantages of electron-tube control.

Constructional Principles and Metallurgical Problems of Welding. D. Rosenthal. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, May–June, pp. 2793–2810). After dealing with the evolution of constructional principles in regard to welded structures, the author discusses the use of structural special steels and the stresses and deformations due to contraction which arise owing to the non-uniformity of the heat application in making welded joints.

Cutting and Welding in the Coke-Oven Industry. (Industrial Gases: Gas World, 1937, vol. 107, Sept. 4, Coking Section, pp. 106–108). An account is given of the repair and maintenance of the plant at the Consett coke-oven works. Fabrication of components from sheet steel by gas welding is described, together with operations such as hard facing with Stellite and flame-hardening.

The Welding and Forms of Laminated Sections. S. Bryla. (Ossature Métallique, 1937, vol. 6, Sept., pp. 416–418). The author compares the shapes of sections used in welded structural work with those used in riveted work, and describes some recently developed forms.

The Welding of Thick-Walled Containers. H. Aureden. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Sept. 11, pp. 1080–1084). In the welding of thick-walled vessels the choice of the shape of weld and the welding process is of importance for the production of perfect welds. The less the quantity of weld metal introduced into a weld, the lower will be the weld stresses. The previously much-used X-weld has given way to the U-weld, the narrow V-weld, and, in particular cases, even to the flat-sided weld. The difficulties encountered in welding increase with the thickness and strength of the plate; it is desirable, therefore, that weld tests should be made throughout on boiler plate with a tensile strength of 47–56 kg. per sq. mm. (German Class IV.) and not less than 50 mm. thick. Unannealed welds can give good strength properties, pro-

vided that a suitable electrode is used. The results obtained are applicable to the welding of heat-resistant boiler plate.

Safe Ending Locomotive Boiler Tubes by Resistance Welding. H. A. Woofter. (Iron Age, 1937, vol. 140, Sept. 2, pp. 32–35). The author describes the development of electric welding technique for the jointing of locomotive flue tubes. The design and construction of flue welders are briefly discussed, and the method of using the " Hartz " roller for rolling down the welds of safe ends is considered.

Corrosion Resistance of Welded Joints. A Review of the Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Aug., Supplement, pp. 1–44). The authors review investigations on the corrosion resistance of gas and arc welds in ferrous and non-ferrous alloys; mild steel, low-alloy steel and stainless steels are discussed. The corrosion-fatigue of welded joints, the corrosion resistance of flame-cut surfaces, and the high-temperature corrosion of welds are also examined.

Rail—Recent Tests and Development. F. R. Layng. (New York Railroad Club : Welding Journal, 1937, vol. 16, Aug., pp. 6–7). The author describes the laying of a length of experimental welded track by the Bessemer and Lake Erie Railroad. The thermit process was employed for welding the rails.

How to Cut Stainless-Clad and Nickel-Clad Steel Plate. H. V. Inskeep. (Welding Journal, 1937, vol. 16, Aug., pp. 2–5). The author describes the technique of levelling and cutting stainless- and nickel-clad sheet by means of the oxy-acetylene cutting jet. The general requirements as to manipulation of the material to be cut are given, together with details of nozzle angles. Hand and machine cutting are dealt with.

MACHINING

Troubles due to Grinding or Machining. R. S. Archer, J. L. Burns and V. Brown. (Metal Progress, 1937, vol. 31, June, pp. 622–625). The authors describe the diagnosis, cause and effect of faulty grinding and machining technique.

Modern Milling-Cutter Forms With Special Consideration of Maintenance of Size. E. Brödner. (Metallwirtschaft, 1937, vol. 16, Sept. 24, pp. 983–988). Operating data for modern milling cutters are presented with particular reference to the choice of cutters for various operations. Types for cast iron and steel are noted.

Higher Charges for Material—Lower Labour Costs, in the Working of Light Metals. H. Brauer. (Metallwirtschaft, 1937, vol. 16, Sept. 24, pp. 997–1000). A detailed comparison between the machining and erection costs of steel and light metals is presented. The necessity of allowing for the easier workability of the latter in estimating production costs is emphasised.

Relation of Size of Spheroids in Tool Steel to its Machinability and to Holding Edge of Cutter. D. E. Roda. (American Society for Metals, Oct., 1937, Preprint No. 10). The quality of a machined surface depends, among other factors, on the ability of the cutter to hold its sharp cutting edge. The author shows how a small difference in the size of the carbide particles in a tool steel makes a great deal of difference in fracturing the cutting edges of cutters. The very stable carbides of iron and manganese can be broken down by annealing the steel for 3 hr. at 1250° F. and cooling in the furnace.

CLEANING AND PICKLING OF METALS

Cleaning of Metallic Surfaces. C. B. F. Young. (Iron Age, 1937, vol. 140, Oct. 14, pp. 185–200; Oct. 21, pp. 40–43). The author reviews in detail the various types of protective coatings which may be applied to metallic surfaces, and discusses surface contamination by inorganic and organic matter which tends to diminish the effectiveness of such protective coatings. The methods of freeing the surface from contamination by the use of emulsifying agents, inorganic cleaning agents such as alkalis, acid pickling solutions, and trisodium phosphate solutions (employed for simple immersion or as an electrolyte in electrolytic cleaning), and organic degreasing agents both of the ordinary hydrocarbon type and of the chlorinated type in the liquid and vapour forms, are considered in detail. The slight toxicity of trichlorethylene is noted, and the danger of cleaning components fouled by sulphonated oils due to the production of free sulphuric acid when these substances react with trichlorethylene is referred to. The possibility of explosions occurring owing to the prolonged contact of trichlorethylene and aluminium swarf is mentioned.

Solvent Degreasing. W. W. Davidson. (Electrochemical Society, Oct. 1937, Preprint No. 15). The solvent degreasing process for the removal of oil and grease from components prior to electroplating or finishing is described in some detail. The fundamental principles of equipment design and the physical and chemical properties of stabilised chlorinated hydrocarbons are briefly noted. Trichlorethylene is particularly referred to, and its satisfactory stabilisation against breakdown and development of free hydrochloric acid due to all adverse conditions except those resulting from exposure to excessive heat or actinic rays, is noted.

Metal Degreasing before Electroplating. (Metal Industry, 1937, vol. 51, Aug. 13, pp. 167–168). A description is given of a degreasing plant employing trichlorethylene in the liquid state for cleaning purposes, particularly prior to electroplating.

The Efficiency of Organic Inhibitors During Pickling of Iron. W. Machu. (Electrochemical Society, Oct. 1937, Preprint No. 3). As opposed to the overvoltage theory, the author advances experimental proof that the action of inhibitors in pickling solutions is due to the greater adsorption of such inhibitors at metallic areas, thus leaving oxidised areas more open to attack by the pickle.

Progress in the Utilisation of Spent Pickle. O. Vogel. (Stahl und Eisen, 1937, vol. 57, Sept. 2, pp. 986–987). An historical account is given of the development of methods for utilising spent pickling solutions.

COATING OF METALS

Testing Methods Employed by the Larger French Railways for Controlling, on Delivery, Electrodeposited Coatings of Nickel and Chromium. P. Biget. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Aug., pp. 478–480). The employment of a drop test for determining the thickness of deposits of nickel and chromium is described. For nickel a solution containing 80 parts of monohydrated nitric acid, 20 parts of sulphuric acid (66° B.) and 40 parts of distilled water is used. For chromium a solution of 40 parts of hydrochloric acid (22° B.) in 60 parts of distilled water is used. The technique of conducting the tests is given.

Drop Tests for Electrodeposited Nickel, and the Specifications of the French Railways. M. Ballay. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Aug., pp. 481–490). The author discusses the technical specifications drawn up by the French Railway Companies regarding electrodeposited nickel and chromium and tests and testing methods for such deposits. A study of the nitric-acid/sulphuric-acid drop-testing solution (referred to in the previous abstract) is then described, the aim of the investigation being to determine the factors affecting the velocity of attack of the solution upon the nickel. The industrial value of the test referred to for nickel deposits below 0·1 mm. in thickness is emphasised. The study of special methods is recommended for the testing of heavier deposits of nickel and chromium employed, for example, for building up worn parts.

A Magnetic Tester for the Thickness of Plating, Galvanising, &c., on Iron Articles. C. E. Richards. (Journal of the Society of Chemical Industry, 1937, vol. 56, Sept., pp. 343–346). The author describes the magnetic testing device suggested by Harris and Williams for determining the thickness of metallic coatings on iron and constructed primarily for industrial use. The instrument is stated to be unsuitable, in the form described, for the determination of very thin coatings, and the " stannometer " of Hoare and Chalmers is referred to as being of value for this purpose. This instrument is also of the magnetic type.

Porosity in Spraying Coatings and its Measurement. E. C. Rollason. (Metallurgia, 1937, vol. 16, Aug., pp. 125–128). The author describes the formation and structure of a sprayed coating, and a number of methods for determining the porosity. Tabular and graphical data are presented.

The *p*H of Alkaline Plating Solutions. G. B. Hogaboom. (American Electro-Platers' Society: Metal Industry, 1937, vol. 51, Sept. 24, pp. 317–320). The results of an investigation of the effects of varying *p*H values on the character of the electro-deposits

from alkaline solutions are presented, and the optimum values for various types of bath are given.

Progress in Electroplating Plant. G. Elszner. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 241–247). The author describes modern plant for polishing and electroplating, and refers particularly to the substitution of electroplated steel and iron for more expensive non-ferrous metals.

Protection by Means of Metallic Surface-Coatings. A Progress Report. A. Kutzelnigg. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 221–241). The author presents a detailed review of methods for applying protective metallic coatings to the surface of metals, and discusses the properties of such coatings and the technique of their application in regard to various metals. Coatings for particular purposes are dealt with and testing methods examined. Galvanised and tinned steel sheet and sprayed coatings on steel are among the subjects dealt with.

Hard Chromium Plating and its Applications. K. Gebauer. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 269–274). The author discusses the causes of the hardness of chromium electrodeposited under certain conditions, and examines the value of such deposits for conferring wear resistance on tools and machine components.

Nickel-Plating Problems. H. Krause. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 266–269). The author refers *inter alia* to the minimum thickness of nickel required to confer corrosion resistance on steel and indicates that whilst an American standard specification gives 0·025 mm. as a desirable value, a nickel deposit 0·010 mm. thick with a thin superposed deposit of chromium has been found more satisfactory than a heavy coating of nickel alone.

Aluminium Coating Successfully Applied to Steel. (Engineering and Mining Journal, 1937, vol. 138, Sept., p. 38). A very brief account is presented of the theory of Fink's hot-dipping process for aluminium-coating steel. Known as Alphate, sheet coated by Fink's process is being commercially produced by the Reynolds Metals Company, Knoxville, Tenn. Its use in the canning industry is referred to.

Clad Sheet. C. Hase. (Metallwirtschaft, 1937, vol. 16, Sept. 24, p. 991). The author briefly discusses the properties of mild-steel sheet clad with copper, nickel, stainless steel, brass and monel metal. The welding technique required for the clad sheet is described.

Clean Electro-Zinc Coatings. E. E. Halls. (Metal Treatment, 1937, vol. 3, Autumn issue, pp. 126–130). The author describes in detail the technique of electrodepositing clean decorative and protective coatings of zinc. The method of preparing the basis surface, the use of electrodeposited undercoats (copper is not recommended, owing to its liability to cause staining), the zinc

electrolyte, washing, subsequent treatments, and lacquering, are all dealt with at length.

Electrolytic Zinc Methods Applied to Galvanising. U. C. Tainton. (American Zinc Institute: Metal Industry, 1937, vol. 51, Aug. 13, pp. 165–166). The production of heavy zinc coatings on iron, employing electrolytic cleaning in fused caustic soda followed by deposition from a high-acid bath at high current density, is described.

The Adaptation of the Tainton Electrolytic-Zinc Process to the Zinc-Coating of Wire and Sheet. G. Eger. (Metallwirtschaft, 1937, vol. 16, Sept. 24, pp. 975–977). The author discusses the Tainton process as applied to the zinc-coating of sheet and wire, and refers particularly to the molten sodium hydroxide electrolytic cleaning process to which material is subjected before applying the zinc coating. The use of the molten hydroxide bath for producing protective films by anodic oxidation is also referred to.

Application of Vertical Gas-Fired Tubes to Galvanising Furnaces. A. M. Thurston. (National Conference on Industrial Gas Sales, Chicago, 1937: Iron Age, 1937, vol. 140, July 29, pp. 38–39: Industrial Heating, 1937, vol. 4, July, pp. 550–552, 566). The author describes the design and construction of galvanising furnaces employing vertical hot-tube heaters installed at the plant of the National Telephone and Supply Co., Cleveland. Natural gas (1100 B.Th.U.) is employed, and increased pot life is anticipated since no flame-impingement occurs.

Contribution on the Formation of Hot-Dipped Zinc Coatings. H. Bablik. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 248–254). The author presents a study of the mechanism of the formation of zinc coatings on steel by hot-dipping, with special reference to equilibrium conditions at the iron/zinc interface, and to the influence of the time and temperature of dipping.

On the Thickness, Bendability, and the Formation of Bloom on Hot-Dipped Zinc-Coated Sheet. H. Grubitsch and F. Brückner. (Korrosion und Metallschutz, 1937, vol. 13, July–Aug., pp. 254–260). As a result of investigations on the properties of hot-dipped zinc-coated steel sheet it is concluded that the structure of the coating depends on the dipping temperature, that at the dipping temperatures employed in practice (430–480° C.) the interface alloy increases rapidly in thickness with increasing time of immersion, and that the dependence of the thickness of the zinc coating on the temperature and time of dipping is approximately equivalent to that of the growth of the alloy layer upon these factors. The bendability is shown to depend on the thickness of the coating and on the time and temperature of dipping. If the optimum dipping temperature and time are exceeded, dull rough microcrystalline deposits are obtained.

Mechanism of "Peeling" of a Zinc Coating. G. F. Comstock. (Metal Progress, 1937, vol. 32, Aug., pp. 162–163). The author advances another hypothesis other than that of Schueler (*see* Journ. I. and S.I., 1937, No. II., p. 147 A) to explain the mechanism of the

" peeling " of galvanised coats, and states that thick hot-dipped zinc coatings on low-carbon steel are not brittle although they may peel on bending the coated steel.

The Methods of Testing Zinc Coatings. L. Kenworthy. (Journal of the Institute of Metals, 1937, vol. 61, pp. 143–169). The measurement of the protective value of zinc coatings on iron and steel, other than by accelerated corrosion tests, is carried out by the examination of the average weight, uniformity, structure and porosity of the coating. The various methods which are in use or have been proposed for carrying out these determinations are described, together with their respective advantages and limitations, and, in certain cases, suggested modifications.

British Standard Method for Testing the Zinc Coating on Galvanised Articles Other than Wire (Copper Sulphate Test and Visual Examination). (British Standards Institution, No. 729–1937).

Rolls Used in Sheet Galvanizing. J. A. Succop. (Steel, 1937, vol. 101, Sept. 6, pp. 66–69, 82). The author describes the mechanical requirements of rolls for galvanising baths and gives brief hints as to the necessary annealing and machining processes. The purpose of preheating rolls before installing is explained, and the necessity for avoiding oxidised surfaces emphasised. The rôle of excessive stressing or heating in causing cracking and breakdown is discussed.

The Electrodeposition of Tin. Part II. Anode Maintenance of an Alkaline Stannate Bath. L. E. Stout and A. H. Baum. (Electrochemical Society, Oct. 1937, Preprint No. 14). A continuation of previous work (*see* Journ. I. and S.I., 1935, No. II., p. 45 A). The tin content of an alkaline-stannate bath is depleted by the precipitation of meta-stannic acid and by unbalanced electrode efficiencies. The former cause is rendered less effective by operating at high alkalinity, but unless suitable precautions are taken, a spongy deposit may result. The value of the critical anode current required to give anodic polarisation, by which means the relative rate of anode corrosion may be varied, depends upon the caustic content in excess of that formed by the hydrolysis of sodium stannate. Control of these factors has been shown to give a bath in which the tin content remains constant for long periods of operation without the addition of oxidising agents such as sodium perborate or hydrogen peroxide.

Refrigerator Parts are Hot Tinned in Unusually Compact Plant. (Steel, 1937, vol. 101, Aug. 9, pp. 51–52, 65). An account is given of the tinning plant at the L. A. Young Spring and Wire Corp., Detroit. A specially compact layout of equipment for cleaning, fluxing, stripping and quenching has been designed. The production cycle is described.

An Acid Test for Tin-Plate. T. N. Morris. (Department of Scientific and Industrial Research, Report of the Director of Food Investigation for the Year 1936, Section VII., pp. 193–195). The

author describes the technique and results of the testing of tinplate for porosity by means of dilute acid. The most satisfactory results were obtained with $N/200$ hydrochloric acid to which was added sulphur dioxide at the rate of 15 parts per million. The attack is measured by estimating colorimetrically the iron taken into solution in the ferrous state by means of $\alpha\alpha$-dipyridyl. A colour standard prepared from cobaltous nitrate is employed.

Metal Spraying (with Special Reference to Adhesion). E. C. Rollason. (Metal Treatment, 1937, vol. 3, Autumn issue, pp. 118–125, 130). The wire-, molten-metal- and powder-fed metal-spraying pistols are described and the merits of each type examined. The adhesion and structure of sprayed coatings are then dealt with in detail, together with various methods of preparing the surface of the metal to be sprayed. Precautions to be taken in safeguarding the health of operatives engaged in spraying or in sandblasting are discussed at some length.

Worn Machine Parts Reclaimed by Spraying. J. S. Martin. (Iron Age, 1937, vol. 140, Aug. 5, pp. 36–38). The use of sprayed monel metal coatings for restoring worn machine elements is described. A rough threaded or grooved surface to receive the deposit is advised; sandblasted or steel-gritted surfaces are said to be unsatisfactory, yielding poor adhesion. Reclamation of wrongly machined work is noted.

The Status of Vitreous Enamelling Technique. L. Vielhaber. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Aug. 21, pp. 982–984). After a preliminary explanation of the chief characteristics of a vitreous enamelled coating, the author describes the preparation of the ground and finish coats and methods of applying them to the steel sheet. The mechanical properties of the enamel in relation to different types of article are noted, and the effect of the shape of the work on the technique adopted is discussed. Raw materials, testing methods and expanded uses are also considered.

Batch Type Enamelling Furnaces. F. S. Markert. (National Conference on Industrial Gas Sales, Chicago, 1937: Industrial Heating, 1937, vol. 4, Aug., pp. 640–641). The author describes radiant-tube batch-type vitreous enamelling furnaces installed by the Ferro Enamel Corp., Cleveland. Structural details and operating costs are discussed.

Principles and Practice of Drying Enamelled Ware. P. G. Pickwell. (Annual Proceedings of the Institute of Vitreous Enamellers, 1937, vol. 3, pp. 75–89). The different conditions required by cast iron and steel sheet during the drying operation are noted.

A Résumé of Some Studies on Sheet Steel Ground Coat Enamels. R. M. King. (Annual Proceedings of the Institute of Vitreous Enamellers, 1937, vol. 3, pp. 203–210). The author examines the problems associated with the causes of the adhesion of vitreous enamels to sheet steel. Attempts to produce a white ground coat are discussed and the causes of "reboiling" are examined.

A Controlled Boiling-Acid Test for Porcelain Enamels. E. E. Bryant. (Journal of the American Ceramic Society, 1937, vol. 20, Oct., pp. 317–319). An account is presented of a newly designed apparatus for the accomplishment of boiling-acid tests on vitreous enamels. The temperature of the acid is controlled, and its volume remains constant; the attack on specimens is limited to a definite area and acid is not wasted because of attack on extraneous parts of the specimen. Quantitative results may be obtained. Data are included in the account to show the accuracy of the method.

The Effect of Iron Surface Preparation Upon Enamel Adherence. K. Krautz. (Journal of the American Ceramic Society, 1937, vol. 20, Sept., pp. 288–295). The author concludes that the original roughness or smoothness of the iron surface before enamelling has little effect on adhesion; the cold-rolled and the etched (sulphuric acid) surfaces give the same impact value, while the sand-blasted surface gives no better adhesion than the smooth nickel-plated surface. The characteristic surface under a fixed ground coat is produced not by reaction between glass and iron but by slow oxidation. Oxidation of the iron prior to fusion of the glass particles is retarded by treatment in oxidising acids and by nickel plating. Thick continuous oxide layers reduce the optimum adhesion figures, while there appears to be no relationship between the adhesion and the degree of surface roughening.

Effect of Manganese, Nickel, and Cobalt Oxide upon the Adherence and Reboiling Properties of a Ground-Coat Enamel. E. E. Howe and R. L. Fellows. (Journal of the American Ceramic Society, 1937, vol. 20, Oct., pp. 319–324). A series of enamels was compounded in which small amounts of adherence-promoting oxides were mixed, and their effect upon the adherence and reboiling properties of a base enamel glass applied to steel was studied. Cobalt oxide was necessary to promote adhesion, but nickel and manganese increased the firing range. Reboiling was found to depend upon adhesion. Micro-examination showed that different phases existed in the interfacial layer when different metallic oxides were introduced into the enamel.

The Painting of Light and Heavy Metals. O. T. Koritnig. (Korrosion und Metallschutz, 1937, vol. 13, Sept., pp. 307–315). The application of " Flintkote " (an emulsion of petroleum asphalt in water) for the protection of steel against the action of sea-water is referred to. The non-flowing properties of the emulsion at high temperatures are noted, as well as its special value in the treatment of structural steelwork owing to its remaining elastic and non-brittle at lower temperatures. The resistance to chemical attack, the necessity for preparing the surface to be treated, and the conditions under which drying should take place are also discussed in regard to " Flintkote." The special requirements of paints for machinery are dealt with, and the different techniques required for cast iron and steel noted. Various oils and drying agents and various systems for accelerating drying are considered.

The Wetting Process in the Grinding of Oil-Colours as Fundamental for Corrosion Prevention by Paint. H. Wolff and G. Zeidler. (Korrosion und Metallschutz, 1937, vol. 13, Sept., pp. 302–307). The authors discuss the effects of grain size and shape and of dispersion of the pigment on the quantity of oil required to produce optimum properties in a paint. They indicate that in many cases, although not in all, the use of a quantity of oil slightly below the optimum amount is less likely adversely to affect the life of the paint than the use of an amount above the optimum level.

Maintenance Problems Simplified by Material Applied Directly Over Rust. (Steel, 1937, vol. 101, Aug. 30, pp. 52–53, 66). The use of a proprietary corrosion-arresting compound applied by spraying or brushing to corroded structural steelwork (bridges and steel towers with riveted joints are referred to) prior to painting is described. The compound is stated to be rapidly absorbed by rust films and to possess some tolerance for water. It may be applied over old paint, or rust, or on clean steel surfaces; loose scale and blistered paint are scratch-brushed off before applying it.

Paint Tests on Iron and Steel. J. C. Hudson. (Transactions of the Oil and Colour Chemists' Association, 1937, vol. 20, Aug., pp. 272–290). The author describes experimental methods of conducting tests on paints applied to iron and steel, some of the major tests made in this field, and possible subjects for future research. Under the first heading accelerated laboratory tests conducted in a "Weatherometer" or some similar instrument, and field tests on relatively small specimens of iron or steel are dealt with; the basis material and surface condition, the control of painting procedure, the dimensions and type of test-piece and the method of exposure, and the methods of grading are discussed. Under the second heading descriptions are given of the field tests carried out in England, the United States of America, Germany, France and Holland, by various associations. The work of private investigators is also referred to, together with that carried out by the Joint Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. Under the heading of possible subjects for future research, the author discusses the prevention of corrosion of iron and steel by the development of corrosion-resistant steels, and more particularly by the use of protective measures.

PROPERTIES AND TESTS

Scientific Research in Various Countries—Belgium. (Recherches et Inventions, 1937, vol. 17, July, p. 147). This is the first of a series of articles concerning the organisation of scientific research in countries that are in touch with the French Office National des Recherches et Inventions. Public interest in national research in Belgium was first aroused in 1916, and in 1920 a law was passed creating a University Foundation to subsidise higher scientific education and research by students and holders of academic appointments. This University Foundation proved insufficient to meet the national needs in 1927, and an appeal was launched under the patronage of King Albert to the banks and industry, as a result of which more than one hundred million Belgian francs (say £700,000) was subscribed. This money was used to endow a public utility organisation called the Fonds National de la Recherche Scientifique. The income of the Fund is administered under statutes made law in June, 1928. These provide for the payment of grants in aid of scientific research work to students and research workers of established scientific ability on scales roughly comparable with those of the Department of Scientific and Industrial Research. Provision is also made for endowing certain scientists occupying a pre-eminent position in science with annuities. Other arrangements include subsidies to industrial research, applications for which are considered by a mixed committee of scientists and industrialists. Of the research subsidised in 1931–1936, that on the behaviour of metals at high temperatures, which includes an investigation of the resistance of cast irons to corrosion, is of direct interest to metallurgists. (A paper describing this work was contributed to the Iron and Steel Institute by Professor Dustin, *see* Journ. I. and S.I., 1934, No. II., pp. 127–151). Details are given of the working of the Fund.

Research on the Progress With Respect to Time, of Stress, Elongation, and Velocity of Elongation in the Tensile Test, Particularly at the Yield Point. A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 13, pp. 187–198). During tensile tests with immediate application of the load and with a highly elastic machine, the course of the stressing, elongation and velocity of elongation were determined by means of an oscillograph. The accepted stress-strain diagram for mild carbon steel was verified up to the yield point. A decrease in stress in the region of necking was observed as in the case of test-pieces stressed in the normal tensile testing machine.

The Flexure of Mild Steels Stressed beyond the Elastic Limit, and the Deflection of Cast Irons. L. Leloup. (Revue Universelle des

Mines, 1937, vol. 13, Sept., pp. 369–380). The author establishes, by consideration of the theories of elasticity, the values of the factor K obtained experimentally by Considère and employed in evaluating the bending effects in mild steel stressed beyond the elastic limit. The factor is also necessary in determining the flexure of cast irons.

Study of a Method of Fluid Pressure Cupping Recommended by Ch. Jovignot. P. Bastien. (Revue de Métallurgie, Mémoires, 1937, vol. 34, May, pp. 339–346). The author describes Jovignot's apparatus for carrying out cupping tests on thin metal sheet by means of oil-pressure, and traces the development of the principle in the hands of Guillery and Gough and Hankins. The properties measured are discussed and treated mathematically, and the value of a registering device is stressed.

Examination of a Method of Cupping by the Jovignot Fluid Pressure. (Sheet Metal Industries, 1937, vol. 11, Aug., pp. 730–744). A complete English translation is presented of the preceding article.

Elimination of the Influence of Gauge in Cupping Tests on Thin Sheets. Marchand. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Aug., pp. 472–474). The author discusses the mathematical treatment of data obtained from cupping tests on the Guillery machine in order to obtain a value independent of variation in thickness of the sheet. To avoid the somewhat lengthy calculations involved, however, a modified type of Guillery machine is suggested, although it is pointed out that where a very wide range of gauges is to be tested, several machines would be necessary to cover the complete series of thicknesses.

The Determination of the Surface Stresses acting at Right Angles to the Longitudinal Direction in the Web of Railway Rails. R. V. Baud. (Organ für die Fortschritte des Eisenbahnwesens, 1937, vol. 92, June 15, pp. 213–222). The author presents a general study of the transverse surface stresses set up in the web of a rail in service, and applies his considerations to two particular designs of cross-section; in one of these designs an increase in the thickness of the upper part of the web causes a reduction in the maximum transverse stress.

New Aspects of Fatigue and Creep. J. M. Lessells. (Metal Progress, 1937, vol. 32, Sept., pp. 257–262). A summary is presented of a series of lectures held at the Massachusetts Institute of Technology. Reference is made to a paper by R. W. Clyne on fatigue in helical springs, in which factors influencing the physical properties of hardened spring steels were discussed. The importance of surface condition is stressed in this connection. The work of Soderberg and of Gough is noted, together with data published by the Verein deutscher Ingenieure. The theoretical aspects of creep are dealt with and the practical significance of the phenomenon is discussed. The high creep and corrosion resistances of a 25% chromium, 12% nickel steel

containing niobium are compared with the lower values given by the 5% chromium steel containing niobium which is now being used in oil-cracking plants. Problems connected with creep are grouped into two classes: Those of a strictly metallurgical nature, and those concerned with the application of creep data to design.

Metallic Damping. S. L. Roberton. (Metal Treatment, 1937, vol. 3, Autumn issue, pp. 138–142, 150). After a brief introduction on the discovery and engineering significance of fatigue phenomena, an account is given of the theoretical aspects of damping capacity and of the importance of this phenomenon in engineering design and construction. The relationships between fatigue strength, stress concentration and notch sensitivity, and the plastic deformation of the material and damping capacity are examined and discussed at length; graphical data are presented and some mathematical treatment is included. Particular attention is paid to the use of damping-capacity investigations as a means of testing the soundness of metal components.

Damped Vibrations in Haulage Ropes. G. Süss. (Glückauf, 1937, vol. 73, Sept. 11, pp. 837–849). The author presents a study of the damped vibrations occurring in mine haulage ropes and in the entire plant, and of the forces which give rise to them.

Fatigue Tests. E. Christol. (Arts et Métiers, 1937, vol. 91, Aug., pp. 173–183). The author discusses the fracture of parts by fatigue, describes three types of fatigue testing machines (the Losenhauzenwerk universal machine, the Schenck flexion or torsion and the Schenck tension-compression machine), and presents a few results obtained with various types of test-piece.

A Continuous Hardness Test: Periodic-Hardness Fluctuations. E. G. Herbert. (British Association: Metallurgia, 1937, vol. 16, Sept., pp. 184–186). The author describes a new hardness test which produces a permanent record of hardness changes occurring in a metal during ageing. The metal is indented by a rotating ball which rolls a groove. Work-hardening and age-hardening may be recorded, and the results are said to be readily expressed in terms of Brinell hardness. The continuous hardness test is used to investigate periodic fluctuations of hardness following magnetic and thermal disturbances; these fluctuations are said to be due to electromagnetic disturbances in the lattice.

Note on the File Scratch Test. W. C. Hamilton. (Metal Progress, 1937, vol. 32, Sept., p. 265). The author notes the value of the file-scratch test for estimating surface hardness. The use of 8-in. square taper files tempered to give a hardness range between 65 and 25 Rockwell C, is recommended; the file ends are ground to needle points. The technique of carrying out a test is described.

Contribution to Knowledge of the Wear Process in the Short-Time Test as Exemplified by Pure Metals. W. Tonn. (Zeitschrift für Metallkunde, 1937, vol. 29, June, pp. 196–198). In order to increase the knowledge concerning comparative wear testing in short-time

tests, experiments were carried out on pure metals, including iron; it was hoped that the fundamental difficulties of wear testing would be revealed more clearly than when using commercial alloys. With pure metals the relative values of the wear resistances fell into different serial orders according to the testing methods and conditions used. The tendency for the wear values to decrease with increasing hardness of the metals was not clearly revealed. According to the test conditions applied, the two rubbing bodies had a mutual influence on each other; for each metal a different type of wear layer was formed, so that the frictional conditions varied from one metal to another. By means of a special testing arrangement with the emery-paper method it was possible to avoid this lack of uniformity of the experimental conditions; the wear values of the pure metals and homogeneous alloys then fell into line with the Brinell hardness values, though this did not apply to heterogeneous alloys.

Mechanically Soft Permanent-Magnet Alloys of Copper, Nickel and Iron. H. Neumann, A. Büchner and H. Reinboth. (Zeitschrift für Metallkunde, 1937, vol. 29, June, pp. 173–185). In the iron-nickel-copper alloy system a field of high magnetic hardness, to which good technological properties correspond, was found. The compositions of the alloys range from about 50 to 90% of copper, about 10 to 50% of nickel and up to about 18% of iron. The magnetic properties of the cast alloys can be much improved by quenching and tempering. Further improvement is obtained by heavy rolling combined with heat treatment. Whereas the remanence was not very sensitive to plastic deformation, elastic tensile stressing raised the coercive force considerably.

Note on the A.C. Method in Permeability Testing. L. G. A. Sims. (British Association, Sept. 8, 1937 : Engineering, 1937, vol. 144, Oct. 1, pp. 387–388). Referring to the proposed issue of a British Standard Specification for a method of testing for incremental magnetisation, the author calls attention to the preference given to the alternating-current method of measuring incremental permeability. The advantages of this practice are discussed, and the requirements are critically examined.

Contribution to Knowledge of the Alloy Kovar. W. Hessenbruch. (Zeitschrift für Metallkunde, 1937, vol. 29, June, pp. 193–195). Under the name "Kovar," also known as "Fernico" in America, an iron-cobalt-nickel alloy is produced of which the temperature-expansion relationship approximates very closely to that of certain glasses, the so-called hard glasses. The composition of the alloy varies between 23·6% of nickel with 29·6% of cobalt and 29·6% of nickel with 17·4% of cobalt; in the former case the manganese amounts to 0·81%, in the latter 0·64%. The alloy resembles closely the irreversible iron-nickel alloys with 34–36% of the latter element. A characteristic of this alloy is that the thermal expansion is very low up to about 200° C., and is dependent on the magnetic transformation of the γ solid solution. Heat treatment between 0° and

1000° C. has practically no effect on the shape of the expansion curve. The author discusses the dependence of the coefficient of expansion of Kovar and hard glasses on the temperature, the influence of heat treatment on the hardness, structure and electrical conductivity of the alloy, and the occurrence of the γ–α transformation in specimens quenched from high temperatures on the application of mechanical stresses.

Mechanical Amplifier with a Magnification greater than 1000. Application to the Recording of the Plastic Deformation of Metals at High Temperature. P. Chevenard and E. Joumier. (Académie des Sciences, July 5, 1937 : Génie Civil, 1937, vol. 111, Aug., 7, pp. 133–134). The limit of magnification with a single-lever amplifier, such as a may be used for measuring very small displacements, is about 200; by introducing a second lever, the magnification is increased, but certain difficulties arise. In the machine referred to here, these troubles are overcome by actuating the second lever, carrying the recording pen, by means of a small servo-motor which is controlled by the first lever. As an example of its use, a diagram of the plastic deformation of a mild steel under load at a raised temperature is given.

Mechanical Properties of Thick-Walled Tubes of Steels such as *LA*5 and *LD*5 of the Baildon Metallurgical Works. I. Feszczenko-Czopiwski, T. Malkiewicz and W. Mazur. (Prace Badawcze Huty Baildon, 1937, No. 2, June, pp. 17–49). The authors describe experiments on low-alloy steels containing carbon 0·25–0·35%, chromium 0·45–0·8%, nickel 1·5–2·0% (*LA*5), and carbon 0·25–0·35%, chromium 0·7–1·1%, nickel 3·25–3·75%, molybdenum 0·2–0·4%, vanadium 0·3–0·4% (*LD*5). Heat treatments, mechanical properties, hardness tests, and microstructures are discussed in detail and tabulated data are presented. (In Polish).

Hydrogen Penetration Phenomena in Steel Cylinder Mercury-Arc Rectifiers. S. H. Hemsley. (Beama Journal, 1937, vol. 41, Sept., pp. 74–76). The author discusses the mechanism of the diffusion of hydrogen, present in the ionic form in the cooling water employed, into the evacuated steel cylinders in mercury-arc rectifiers. The effects of diffused hydrogen and the various agents and conditions favourable to the diffusion process are considered. Experiments appear to indicate that corrosion and hydrogen penetration in rectifiers are definitely interrelated. The use of 3–6% chromium steels for high-pressure hydrogenating plant is noted and the satisfactory performance of 0·9% chromium steel in service is also dealt with; in both types of steel the carbon contents are critical. Chromium decreases the permeability of steel to hydrogen. For rectifiers a steel containing 18% of chromium, 8% of nickel, 0·5% of tungsten and 0·5% of titanium, has proved satisfactory. Machining and welding operations are readily carried out and no subsequent heat treatment is required. The development of an equally satisfactory but less expensive steel is considered advisable.

Effect of Hydrogen on Steel. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 60–63, 59). An abridged English translation of an article by P. Bardenheuer, the original of which appeared in Stahl und Eisen, 1937, vol. 57, May 27, pp. 593–599. (*See* Journ. I. and S.I., 1937, No. II., p. 157 A).

The Physical and Mechanical Properties of Pure Iron as a Function of Cold-Work. W. Broniewski and I. St. Glotz. (Comptes Rendus, 1937, vol. 204, pp. 1473–1475). The authors present a diagram in which the variations of a number of physical and mechanical properties with the degree of cold-work applied are indicated. The metal used was electrolytic iron containing only 0·004% of phosphorus and 0·001% of sulphur as impurities; it was melted in a high-frequency furnace *in vacuo* and was allowed to solidify under pressure.

Some Physical and Chemical Properties of Very Pure Steels. W. Broniewski, S. Przedpelski and S. Sulowski. (Comptes Rendus, 1937, vol. 204, pp. 1874–1876). The authors present briefly the results of a study of some of the physical and mechanical properties and also the microstructure of iron-carbon alloys of high purity. These were prepared by melting electrolytic iron and carbon prepared from turpentine in a high-frequency vacuum furnace, using crucibles of fused pure magnesia. The analysis of the basis metal was 0·010% of silicon, 0·002% of phosphorus, 0·0005% of sulphur, with an indeterminable trace of manganese; the total impurities did not exceed 0·014%.

The Present Status of the Superheating-Melting of Cast Iron. E. Piwowarsky. (Giesserei, 1937, vol. 24, Oct. 8, pp. 510–517). The author traces the evolution of modern cast irons and of the practice of superheating the melt to obtain improved mechanical properties. The constitution of molten iron-carbon alloys is discussed with special reference to the velocity of solution of graphite. The influence of superheating on the primary-crystallisation processes and its importance in connection with the melting of steel and non-ferrous metals are considered.

The Properties of Sheet Metal. J. D. Jevons. (Metal Industry, 1937, vol. 51, Aug. 6, pp. 127–131; Aug. 13, pp. 157–161; Aug. 20, pp. 181–184; Aug. 27, pp. 207–210; Sept. 3, pp. 227–231; Sept. 24, pp. 310–313; Oct. 1, pp. 335–340). The author discusses the nature of the properties of sheet metal required for deep-drawing and stamping operations. Methods of testing, and the limitations of such methods, together with properties commonly specified are dealt with.

Present Trends in Alloy Steels. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 67–69, 74). An abridged translation into English of a paper by J. Galibourg the original of which appeared in the Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1936, vol. 135, Aug.–Sept., pp. 545–567. (*See* Journ. I. and S.I., 1937, No. I., p. 83 A).

10Cu + 18Cr + 72Fe, etc. = Digby's Cypritic Alloy, an Entirely New Species of the Genus Stainless Steel. T. W. Lippert. (Iron Age, 1937, vol. 140, Oct. 14, pp. 54–63). The author presents a detailed account of the history, metallography, mechanical and physical properties, behaviour towards corrosive agents (including weathering), workability, and production and machining costs of the 10% copper, 18% chromium steel developed by W. P. Digby. The carbon contents of two grades of the "cypritic" steel noted in detail vary from 0·05 to 0·09%, and in both cases the manganese and silicon do not exceed approximately 0·4% each. The heterogeneous nature of the alloy is commented on at some length. The presence of a copper-rich phase termed "cyprite" is indicated. Unlike the normal stainless steels of the austenitic type, the corrosion-resisting characteristics of which are said to be approached by those of the new alloy, the copper-chromium cypritic steels are wholly ferritic.

The Mechanical Properties of Heat-Resisting Chromium-Aluminium-Iron Alloys. W. Hessenbruch. (Elektrowärme, 1937, vol. 7, p. 7 : Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Oct. 30, pp. 1285–1286). The author presents data on the mechanical properties of three alloys containing 5% of aluminium and 20, 25 and 30% of chromium, the rest being iron. These alloys are suitable for making resistance heating elements, provided that attention is paid to the fact that, if they are held at temperatures above 800° C. for any length of time, they become brittle and grain growth sets in. Their properties are compared with those of nickel-chromium alloys; the tensile strength after suitable heat treatment (heating for 2 hr. at 600–800° C. followed by oil-quenching) is about the same as that of the nickel-chromium alloys (80/20, or 60/18·5 plus iron), the elongation is much less and the Brinell hardness greater; they are ferritic in microstructure and are not hardened by cold-work. The hot tensile strength is less than that of the nickel-chromium alloys, and the creep limit is also lower by 200–300° C. Prolonged heating at 400–500° C. also sets up brittleness.

Comparative Investigation of the Mechanical Properties of Nickel-Bearing and Nickel-Free Steels, With Particular Regard to their Behaviour under Vibratory Stress. A. Pomp and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 16, pp. 221–236). Twenty-one steels, some containing nickel and others nickel-free, were examined under identical conditions in order to determine from the mechanical properties so obtained when the use of any particular type of steel is indicated. It is shown that for tensile strengths between 120 and 130 kg. per sq. mm., steels containing 2·5 to 4·5% of nickel with additions of tungsten and molybdenum gave no better results than 1–2% nickel steels with additions of chromium and molybdenum. For tensile strengths of the order of 90 to 100 kg. per sq. mm., the 1–2% nickel steels and even nickel-free steels proved quite

satisfactory. Data are presented in graphical and tabular form.

Graphitic Steel. Its Fabrication, Heat Treatment and Application to Dies and Punches. G. A. Stumpf and F. R. Bonte. (Steel, 1937, vol. 101, Aug. 30, pp. 34–39). The authors describe the metallography and mechanical properties of graphitic steels; two brands are referred to: "Graph-sil" for water-hardening and "Graph-mo," which contains 0·25% of molybdenum to minimise distortion, for oil-hardening. The heat treatments and resultant mechanical properties are discussed, and some details of the use of these steels in the manufacture of punches and dies are given.

Graphitic Steel. Its Fabrication, Heat Treatment and Application to Dies and Punches. G. A. Stumpf and F. R. Bonte. (Heat Treating and Forging, 1937, vol. 23, Aug., pp. 380–385). (*See* Journ. I. and S.I., 1937, No. II., p. 279 A).

Metallurgy and the Aero-Engine. D. R. Pye. (Institute of Metals: Metal Treatment, 1937, vol. 3, Autumn issue, pp. 107–113, 117). Good machining qualities and the capability of responding to special surface treatment on the working face are stressed as desirable properties in a steel for aero-engine cylinder barrels. The special properties which render cast iron an ideal material for piston rings in spite of its otherwise poor physical and mechanical properties are discussed, together with the amorphous-layer hypothesis of Beilby and the practical significance of the layer. Problems connected with the resistance to scaling of valves at high temperatures and with their resistance to attack in the heated state by lead compounds are also dealt with; reference is made to the use of steels containing 12 to 14% each of nickel and chromium and to the practice of hard-facing with Stellite, and, more recently, to the use of an alloy containing 80% of nickel and 20% of chromium for replacing Stellite. The use of sodium and mercury-filled valves for obtaining more rapid heat transference is examined.

Tool Steels. A. Michel. (Métaux, 1936, vol. 11, Nov., pp. 217–222). The continuation of a series of articles (*see* Journ. I. and S.I., 1936, No. II., p. 266 A). In the present instalment the author discusses the properties required in tool steels for various types of tools and methods of testing them.

The Control of High Pressures in Closed Vessels, with Special Regard to Bolts as Constituting the Most Frequently Recurring Part of the Closure. A. F. Maier. (Technische Mitteilungen Krupp, 1937, vol. 5, Oct., pp. 197–214). The mechanical and physical requirements of bolts and screwed joints for high-pressure, high-temperature vessels are examined from a mathematical standpoint.

On the Breaking of a Cable of a Cage. J. Venter. (Annales des Mines de Belgique, 1937, vol. 38, No. 2, pp. 343–357). A detailed account is presented of an investigation into the causes of the fracture of a wire cable forming part of the winding gear of a coal mine in Liége. Corrosion was the primary cause of failure.

METALLOGRAPHY AND CONSTITUTION

The Application of Modern Microscopes in Metallurgy. A. Salmony. (Metallurgia, 1937, vol. 16, Aug., pp. 115–117). The author describes the modern microscope and discusses advances in the technique of microscopy in relation to metallurgical research and in routine applications made possible by modern instruments of the types referred to.

Application of the Phenomena of the Diffraction of X-Rays to the Study of Metals and their Alloys. J. Thomas. (Mémorial de l'Artillerie Française, 1937, vol. 16, pp. 227–249). The author first discusses the theory and practice of the examination of the structure of metals by means of X-rays, and then summarises general information regarding X-rays and crystalline structure.

Hollow-Anode Tubes for X-Ray Work. E. A. W. Müller. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Oct. 2, p. 1175). A description is given of an X-ray tube suitable for the investigation of welds in steel.

The Development of the Structure in Cast Iron and its Relation to Foreign Bodies giving Rise to Nuclei in the Melt. E. Diepschlag. (Giesserei, 1937, vol. 24, Aug. 27, pp. 437–441). The author discusses the development of the structure in cast iron and the influence exerted on it by the action of various foreign bodies in the melt which give rise to the formation of nuclei; he deals with the freezing process, the conditions within the hearth of the blast-furnace, the formation of nuclei and nuclear action.

Some Observations on the Addition of Silicon and Tin to Grey Iron. E. Valenta and N. Chvorinor. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Sept. 16, pp. 228–232). The authors describe and discuss experimental work in connection with the modification of the graphitic structure of cast iron by the addition of silicon under various conditions; the varying effects of such additions on the mechanical properties are noted. The effects of tin, up to 2%, on the mechanical properties, particularly on wear resistance, are also dealt with.

Grain Size in Steel. Estimation, Effect and Control. (Iron and Coal Trades Review, 1937, vol. 135, Sept. 3, p. 368; Sept. 10, pp. 401–402). An abridged English translation of a paper by E. Houdremont and H. Schrader the original of which appeared in Stahl und Eisen, 1936, vol. 56, Nov. 26, pp. 1412–1422. (*See* Journ. I. and S.I., 1937, No. I., p. 88 A).

The Modifications of the Grain Size of Mild Steel after Cold-Working and Reheating. P. Duwez. (Publications de l'Association des Ingénieurs de l'École des Mines de Mons, 1937, No. 61, pp. 233–256). This paper is divided into two parts. In Chapter I. the author deals with an experimental study of the growth of the grain

size in mild steel. After reviewing the present position of the problem, he discusses the factors influencing grain growth, and then describes his experimental apparatus for examining the influence of the reheating temperature on the grain size. Tests on specimens cold-worked to various degrees indicate that the grain size of mild steel (carbon $< 0{\cdot}02\%$, impurities $< 0{\cdot}05\%$) grows abnormally when the reheating temperature lies between 720° (A_1) and 906° C. (A_3); the final size is independent of the temperature within this range. The degree of cold-working does not shift the limits of this range of critical temperatures, but it does affect the size of the grains after reheating. The author next deals with the influence of cold-work on the grain size after reheating in the critical range (the temperature of 825° C. was selected); diagrams show that the grain size (after reheating) varies with the degree of cold-working, maximum growth occurring with cold-working to the extent of $2{\cdot}8\%$, and that the rate of growth decreases with time, being virtually zero at the end of two hours. Chapter II. is concerned with the mechanism of re-crystallisation; cold-work and the crystal lattice, recrystallisation in the strict sense of the word, the hypothesis of centres of crystallisation and the growth of grains, and the hypothesis of variations of equilibrium and grain growth between A_1 and A_3 are subjects discussed.

The Effect of Pouring Time on the Grain Size of Austenite in Open-Hearth Steels Subjected at the Transformation Point to the Action of Various Quantities of Aluminium in the Ladle. I. Feszczenko-Czopiwski and T. Palmrich. (Prace Badawcze Huty Baildon, 1937, No. 2, June, pp. 49–60). The authors review in some detail previous work and theories on the effect of aluminium on the grain size of austenite and then describe fully experiments on a $0{\cdot}39\%$ carbon open-hearth steel with additions of aluminium up to $0{\cdot}04\%$. (In Polish).

Investigation of Optimum Conditions of Cementation by Means of the Determination of the Primary Grain Size of the Austenite by the McQuaid-Ehn Method. I. Feszczenko-Czopiwski and A. Stanislawski. (Prace Badawcze Huty Baildon, 1937, No. 2, June, pp. 61–73). Hypereutectoid, eutectoid and hypo-eutectoid steels were carburised with carbon/barium-carbonate mixtures for periods between 4 and 12 hr. and at temperatures between 850° C. and 1050° C. Optimum conditions in each case were deduced from curves giving the final grain size in millimeters. (In Polish).

The Freezing of Cast Iron. A. Boyles. (Transactions of the American Institute of Mining and Metallurgical Engineers, 1937, Iron and Steel Division, vol. 125, pp. 141–203). The mechanism of freezing in hypo-eutectic cast iron was studied by quenching small melts from various temperatures during slow cooling. Primary austenite is precipitated as dendrites, which continue to grow down to the eutectic temperature. Crystallisation of the eutectic begins at various centres which grow equally in all directions, forming a cell-

like structure. Segregation takes place in two stages, (1) between the primary dendrites and the liquid, and (2) from the crystallisation centres outwards into the boundaries of the cells. Constituents formed during the freezing of the eutectic occupy the interstices of the dendrites. Graphite flakes and phosphide eutectic are thus restricted by the size and distribution of the dendrites. Alloys of iron, carbon and silicon were found to freeze in the same manner as cast iron, but their structure was modified. Additions of manganese and sulphur to such alloys produced normal structures. By melting cast iron under reduced pressure and remelting it in hydrogen, the change from a modified to a normal structure could be reversed at will. This was attributed to the introduction and removal of hydrogen. On the basis of such evidence a hypothesis was proposed to explain the phenomenon of modification in cast iron.

The Course of the Austenitic Transformation in the Supercooled Condition, according to Investigations on Pure Carbon Steels. H. Lange and H. Hänsel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 14, pp. 199–208). Researches on the austenitic transformation in a hypereutectoid steel have enabled a transformation diagram to be constructed by means of which variations of the transformation with respect to temperature and time for all conditions of cooling may be determined. The influence of heat evolution on the transformation temperature and on the time-course of the transformation was investigated, and Wever and Engel's transformation diagram for hypereutectoid steels showing the influence of the cooling rate on the transformation, is explained. Agreement was found between the authors' work and that of Wever and Hänsel on the austenitic transformation in a supercooled melt between 700° C. and the martensite point. Troostite produced by quenching was found to be capable of resolution into pearlite, when sections were prepared with the necessary care. The value of the transformation diagram as a basis for explaining the transformation phenomena revealed by the cooling curves is discussed.

Nature of the Iron-Manganese Alloys. F. M. Walters. (Metal Progress, 1937, vol. 32, Sept., pp. 254–255). The author compares and contrasts the iron-manganese and the iron-nickel systems. The equilibrium diagrams are compared in detail, and the metallography of the iron-manganese alloys is discussed with particular reference to the high-manganese alloys.

CORROSION OF IRON AND STEEL

Dutch Organisation of the Fight against Corrosion. G. Batta. (Revue Universelle des Mines, 1937, vol. 13, Aug., pp. 348–350). A brief account of the activities of the Dutch Corrosion Committee is given.

Corrosion of Metals. A. Leroy. (Revue de la Soudure Autogène, 1937, vol. 29, Oct., pp. 226–234). After a general review of the phenomena of corrosion, the author discusses the influence of heterogeneity in the metal and in the solution by which it is attacked, the appearance of corroded metals and the consequences of corrosion, and the relative effects of various factors in corrosion. Then, after a brief reference to the fight against corrosion, the influence of welding on corrodibility is dealt with.

Electron Diffraction Studies of Oxides formed on Iron. T. Iimori. (Nature, 1937, vol. 140, Aug. 14, p. 278). The author describes briefly the results of an examination of oxide films on iron by electron diffraction methods. He concluded that the oxide formed below 340° C. is γFe_2O_3, and that the $\alpha \rightleftharpoons \gamma$ transformation point lies at about 340° C. The unknown primary oxide formed by heating for a short time at 200° C. and 250° C. is to be further investigated.

Electrode Potentials. Relation to Corrosion of Alloys and Metals in Lubricating Oils. F. Hovorka and J. K. Anthony. (Industrial and Engineering Chemistry, 1937, vol. 29, Aug., pp. 959–962). Data are presented on the electrode potentials of various bearing metals and alloys in several lubricating oils. Potentials were found to start at about 110° C. in unstirred cells and at about 70° C. in stirred cells. Voltages as high as 1·1 were found at 170° C. Potentials varied considerably with temperature, and a reversal of polarity was frequently found. The possible correlation of such potentials with the problem of the corrosion of bearings is discussed.

Electrochemical Protection of Iron from Corrosion in Alkalies. W. W. Stender, B. P. Artamonow and V. K. J. Bogojawlensky. (Transactions of the Electrochemical Society, 1937, vol. 72, pp. 389–411). Determinations were made of the rate of corrosion of electrolytic iron, cast iron, and sheet iron in concentrated solutions of sodium and potassium hydroxides, fused alkali hydroxides, and in alkali lyes during the process of fusion. The rate of corrosion was found to depend on the temperature, the concentration of the alkali, and the concentration of chlorine ions and chlorate ions in the solution. The effect of cathodic polarisation on the rate of corrosion of cast iron and sheet iron was studied, the above factors being varied. For the electrolytes examined, cathodic polarisation was found to protect the iron against corrosion; the ratio between the current density without applied cathodic polarisation and the current

density with applied cathodic polarisation was found to vary between the limits of 0·20 and 0·37 amp. per sq. mm. Cathodic polarisation gives only partial protection against corrosion to an iron container during and after fusion of the alkali.

A New Method of Corrosion Testing. J. Cournot and M. Chaussain. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Aug., pp. 475–477). The authors describe a method of corrosion testing in which the specimen is, initially, entirely immersed in the liquid corrosive medium, which is then allowed to evaporate until the specimen is fully exposed. Comparative tests between this and other corrosion tests involving immersion of the specimen in various ways are described. It is pointed out that the new method possesses limitations which in general render it difficult to standardise and unsuitable for general practice. Its value for testing protective surface coatings is referred to.

Effects of Corrosion on Cast-Iron and Steel Piping. L. Olsansky. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Oct. 28, pp. 341–342). The author describes experimental work carried out to determine the causes of the corrosion of the inner and outer surfaces of cast-iron and steel pipes; the chemical, electrical and electro-chemical aspects of the problem were studied, and the penetration and rapidity of corrosion with respect to the thickness and structure of the metal forming the walls were determined. The paper contains no general conclusions; these are to form the subject of a further communication.

BOOK NOTICES

BUELL, W. C., jun. "*The Open-Hearth Furnace. Its Design, Construction and Practice.*" Vol. II. 8vo. pp. ix + 260. Illustrated. Cleveland, Ohio, and London, 1937: Penton Publishing Co. (Price 17*s.* 6*d.*)

Volume I. of this series dealt with the refractories and the design and construction of the furnace. Volume II., which has now appeared, deals with the metallurgical problems and the influence of design in carrying out the process. The book is divided into twelve chapters, eleven of which are devoted to the metallurgical side, each chapter being dependent on the previous one. From the furnace designer's and the steelmaker's point of view, Chapter II. is most valuable. It gives details of the areas and designs of ports and also a critical analysis of the defects of each. Table 71, p. 52, will repay careful study, and it will be seen that few furnace designs meet all the conditions laid down. On p. 54 the author says, "A perusal of the figures, column *h* of Table 71, reveals the rather startling data, that, based on the correct requirements of the design necessary to secure satisfactory overall operation, only two furnaces designed for producer-gas firing meet the minimum requirements of the critical areas in all respects." The other chapters are all equally valuable, but attention should be drawn to Chapter IV., on fuel rates and fluid flow. This chapter deals with the velocities of the products at various points of the furnace, and gives a method for their calculation. The furnaces described in Chapter II. are again analysed here, and from the velocities calculated indications are given showing where improvement can be made. Useful data on the development and use of the area-temperature-velocity diagram are given in Chapter VI., which if used as a basis for works comparison, will be of great value. As a book of reference and for comparison with existing designs, this volume will prove extremely valuable. It is a great pity, however, that American publications, such as this, should continue to give their temperatures in degrees Fahrenheit.

T. M. SERVICE.

LEIER, F. W. "*Hartmetalle in der Werkstatt.*" (Werkstattbücher. Heft. 62). 8vo. pp. 53. Illustrated. Berlin, 1937: Verlag von Julius Springer. (Price 2 marks.)

This booklet gives an account of the treatment and applications of hard-metal alloys of the sintered carbide type. The information given relates only to the three varieties of the material produced in Germany, namely, Widia, Titanit, and Böhlerit, but is, of course, applicable to any product of similar composition. The three types mentioned are described in some detail and the applications of the various qualities are indicated. This is followed by a series of tables and sketches giving the dimensions of the carbide "nibs" necessary to tip a wide range of sizes of lathe tools and drills. The precautions to be observed in making tipped tools are next considered, the stiffness of the shaft, the adequate support of the tip, and the method of brazing the tip on to the tool, all being dealt with in turn. The tipped tool must finally be ground to a cutting edge and this process is described in some detail. The only grinding medium of practical importance is

carborundum, and the precautions to be observed, particularly in regard to cooling the tool during grinding, are emphasised and illustrated by sketches and photographs. In certain cases lapping may also be carried out on cast-iron wheels dressed with diamond dust or crushed boron carbide, and this operation is described and illustrated. Later sections deal with the proper and economical use of tipped tools in the machine shop, tool settings for various operations being given and the requirements of the machine tool itself stated. Comprehensive tables give the tool profile and cutting speeds and feeds for machining a wide variety of materials, using the three brands of sintered carbide already mentioned. The advantages and limitations of carbide cutting alloys are clearly demonstrated, and the book will form a valuable guide to those seeking instruction in the proper employment of these modern materials.

STEPHEN L. ROBERTON.

MIKLÓSI, C., and C. C. TEODORESCU. "*Procedeele Industriale de Sudură.*" 8vo. Vol. I. pp. 226 with a bibliography. Vol. II. pp. 377. Illustrated. Bucharest, 1936: Institutul Român de Energie.

The first volume of this treatise on welding is a short review of the fundamental knowledge about metals and alloys. After a description of the general structure of matter and a definition of the three physical states—gaseous, liquid, and solid—the theory and analysis of crystals are explained; the definitions of polycrystalline metals, of the allotropic forms of substances and of solid solutions, and finally that of alloys are given. Next the mechanical properties of pure metals are treated, these being divided in two classes, plastic and brittle. The testing methods are sketched. Recrystallisation, internal stresses, and the influence of temperature and of the speed of deformation upon the mechanical properties are explained, and then figures concerning the physical properties of pure metals are quoted. The characteristic types of binary alloys and the methods of their preparation are described; short chapters deal with the intermetallic compounds of metals, with gases in metals, with segregation and with piping. The physical properties of alloys are then discussed. The alloys of iron, in the first place the carbon steels, their heat treatment and impurities are next shortly described, then a review of the special steels is given. The influence of the chemical composition and of the heat treatment upon the properties of the alloys of iron is taken into consideration. A description of the alloys of copper, of aluminium, &c., close this volume. The second volume deals with the technology of welding. A rational and primarily practical classification of welding methods is deduced, the latter being adopted as basis of the treatise. The fire-welding of the various metals is treated in a short chapter; the next deals with electric welding "by local heating," which is classified as butt-welding (resistance-, spot-, shot-welding), spot welding, and seam welding. The book describes first the electrical system of the apparatus used and then the mechanical features of them. This is followed by metallurgical considerations on the behaviour of the various metals and alloys assembled by the welding methods in question. The chapter is closed by a short description of resistance and induction heating systems. The major part of the second volume is reserved for fusion welding. Here the physical properties of the gases used in welding—oxygen, acetylene, hydrogen, methane, butane, town-gas and benzol—are enumerated, then gas generators, and safety-valves and their manipulation are described, followed by the gas-cylinders, the reducing valves, welding torches and

the arrangement of welding shops. Finally, welding methods are discussed. The electric arc is then treated as another means of fusion-welding. An analysis of the generation of the electric current for welding purposes, direct and alternating, is given. Finally the accessories and working methods are explained. The question of the welding wire and electrodes is then taken into consideration. Next follows a description of the apparatus, the alloys and fluxes used for soldering and brazing. An ample explanation of the metallurgical phenomena in the fusion-welding of carbon steels is given, together with a discussion on weldability, determinant metallurgical factors, mechanical properties of welds, thermal phenomena and internal stresses, and heat energy consumed. After an analysis of the welding of special steels, that of cast iron on cold and hot pieces is described. These metallurgical considerations are closed with the welding of copper, of nickel, of aluminium, of magnesium and their alloys and finally with that of lead and zinc. The following chapter deals with the calculation of costs with examples. The applications of fusion-welding are then shown ; girders, workshop equipment, bridges, railway-carriages, containers, pipe-work, boilers, machines, welded rails and then some cases of repair are described. Work done by the Rumanian industry is especially considered. The book then deals with gas-cutting. The volume closes with an account of alumino-thermic welding. The third volume, in preparation, will deal with normalisation, with the strength of welded structures, the control of welding and finally with accident prevention.

SCHOELLER, W. R. "*The Analytical Chemistry of Tantalum and Niobium.*" The Analysis of their Minerals and the Application of Tannin in Gravimetric Analysis. Based upon Original Researches. With a Foreword by G. Roche Lynch. 8vo. pp. xvi + 198. London, 1937 : Chapman & Hall, Ltd. (Price 21*s.*)

This book is based on the original researches of Dr. Schoeller and his co-workers on the analytical chemistry of tantalum, niobium and their mineral associates. It is not confined to those elements, but gives comprehensive methods for the quantitative separation and determination of a large number of the so-called rare elements, and in particular deals with the use of tannin in such separations and determinations. For many years the analytical separation of tantalum and niobium has presented difficulties, and the frequent association of titanium has, as the author states, provided one of the most baffling problems in the whole range of analytical chemistry. A solution containing compounds of several of these elements may, on hydrolysis, give rise to very complex precipitates. Separation of the constituents from these complex precipitates seems to be impossible, and the author has amply verified the conclusion that all separation methods must proceed from a common solution of the constituents to be separated. For the purpose of the separation, various complexes of the earth-acids, &c., with organic hydroxy-acids have been employed. Analytical methods using these complexes are described, but the greatest success has been obtained by the employment of tannin. The book is divided into three parts. Part 1 gives an account of the compounds of tantalum and of niobium which are of analytical importance. Such compounds as the pentafluorides, tartaro-acids, oxalo-acids, tannin and salicylic complexes are included, and the chemical compositions of tantalum and niobium minerals are discussed. One chapter deals with analytical technique, which should be of considerable assistance to those undertaking these rather difficult separations for the first time. Other chapters give the

tartaric acid method for the analysis of the tantalo-niobate minerals and the hydrofluoric method for the analysis of the titano-niobate minerals of the rare earths. Part 2 describes quantitative methods for separations of tungstic oxide from the earths, thoria and rare earths from other earths, the earth-acids and titania from other earths, tantalum from niobium, &c. Special methods are also given for the determination of small amounts of such constituents as the rare earths in tantalic and niobic oxides, tantalum in niobic oxide, niobium in tantalic oxide, &c. Part 3 is devoted to the applications of tannin in gravimetric analysis. Dr. Schoeller states that tannin has rapidly acquired paramount importance in the analysis of minerals and alloys containing earth-forming metals, and is absolutely indispensable in the analytical chemistry of tantalum, niobium and titanium. Owing to its property of forming complexes with the earth-acids, &c., many otherwise difficult separations can be made, such as, for example, the quantitative separation of tantalum from niobium. Another property is that some of the tannin complexes possess characteristic colours, which are of great importance in the detection and identification of elements which form colourless solutions. The use of tannin is not confined to the earth-acids, and examples are given of many applications, such as in the separation of aluminium from iron, &c. It is impossible to mention all the separations and determinations which are the subject of the book, but it may be said that it is the most complete account of the analytical chemistry of the earth-acids that has so far appeared, and will prove of inestimable value to any worker in that or allied fields.

E. W. YEOMAN.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Gemeinfassliche Darstellung, des Eisenhüttenwesens.*" Herausgegeben vom Verein deutscher Eisenhüttenleute in Düsseldorf. 14 Auflage. la. 8vo. pp. xii + 591. Düsseldorf, 1937: Verlag Stahleisen m.b.H. (Price 15 marks.)

This is the fourteenth edition of a work that first appeared in 1889, the present volume being issued in a larger format than its predecessors, and with all sections brought up to date by contributions from members of the Verein. The book is a simple account of the iron and steel industry, but this simplicity is achieved largely by clarity of treatment, and not by omission. Thus, although the work may be termed "popular," it gives a survey of the industry that must be of interest to laymen and technicians alike. The first part of the book covers the metallurgy of iron and steel. A short historical section is followed by a chapter on the raw materials of the industry, with a description of metallurgical coke plant and a short account of refractory materials. The next two chapters deal with the production of pig iron and steel respectively, and thereafter follow accounts of casting, forging, and rolling practice, and the testing of the finished material. This account of the technical side of the industry is illustrated with most admirable photographs and diagrams, and schematic flow-sheets are also given of certain of the operations described. In the chapter on testing a short account is given of the iron-carbon diagram, and typical microstructures are shown in a series of excellent photographs. Practically every aspect of the iron and steel industry is touched upon, and a more complete introduction to the subject can hardly be imagined. The second half of the book is, surprisingly but logically, an account of the world economic position of the industry, considered under various headings. Statistics are given for the iron and steel output of all the producing countries,

and the condition of the industry and the position as regards raw materials are considered at greater length for each country separately in a following chapter. The evolution and organisation of the German industry are described in two chapters, and international trade agreements, cartels and world prices are dealt with in later sections. An account of the new structure of the industry in Germany according to National Socialist principles, and a list of iron and steel works in Germany concludes the volume. The book is remarkable for its scope and thoroughness, and will combine interest and enlightenment for all its readers. The binding and printing are excellent, and the publishers are to be complimented on producing such a fine work at so moderate a price.

STEPHEN L. ROBERTON.

VOGEL, R. "*Die heterogenen Gleichgewichte.*" (Handbuch der Metallphysik. Band II.) la. 8vo. pp. xxiii + 737 with 491 illustrations. Leipzig, 1937 : Akademische Verlagsgesellschaft. m.b.H. (Price 68 marks.)

This is the second volume of a general series on the physics of metals published under the editorship of Prof. Dr. G. Masing of Berlin-Siemensstadt. In the foreword it is stated that although this volume is nominally devoted to metals, the study of heterogeneous equilibria covers a much wider scope, and it has been considered expedient to deal more or less fully with non-metallic systems also in order to present a comprehensive account of the subject. The work as a whole can leave little unsaid regarding the application of the principles of heterogeneous equilibria to metallic systems, or indeed to any system, and, appearing at a time when the examination of alloys in the light of classical physico-chemical theory is making rapid progress, the volume constitutes a valuable addition to available sources of information. The author commences his treatment of the subject by establishing the definitions of the terms used, the thermodynamical theory of equilibrium, and the implications of the phase rule. Thereafter the study is begun of the equilibrium between the gaseous, liquid and solid states in single components, including cases where polymorphism occurs. The initial study of binary systems is concerned with the relationship between the gaseous and the liquid states, and proceeds to the consideration of liquid-solid equilibria in the absence of the gaseous phase. Here the metallurgist enters on the familiar ground of the equilibrium diagrams of binary metallic systems, but long before this stage he will have realised that the complicated relationships that have to be studied in the crystallisation and transformation of alloys are merely examples of general phenomena that occur again and again in the phase relationships of all substances, solid, liquid or gaseous. The later, and greater part of the book is taken up with the study of ternary systems, with a short final section on quaternary systems, all of which is directly applicable to the study of alloys, since the vapour phase is neglected except in an introductory section. The treatment of systems with more than two components is complicated in itself, and still more so owing to the difficulty of rendering three-dimensional diagrams on a plane surface, but the illustrative diagrams in this part of the book are clearly printed, and should present the minimum of difficulty to the reader. The work is one that will recommend itself to all physical metallurgists as a detailed and comprehensive account of much that is fundamental in the study of alloy systems, and as a clear exposition of the phenomena of equilibrium in metallurgy and chemistry. The book is well bound and printed, the arrangement and indexing leave nothing to be desired, and documentary references are comprehensive and up to date.

STEPHEN L. ROBERTON.

MINERAL RESOURCES

The Mineral Resources of Hyderabad. K. Mirza. (Hyderabad Geological Series, Bulletin No. 2 : Bulletin of the Imperial Institute, 1937, vol. 35, July–Sept., pp. 365–367). Reference is made to the exploitation of coal in Singareni, Tandur and Sasti, and the existence of coal in other areas is noted. The wide distribution of iron ore is commented upon and its inability to compete with high-grade ores cheaply mined elsewhere in India is discussed. Manganese deposits occur in certain areas and these might repay investigation.

The Ore Deposits and Ore Production of Finland. M. Saksela. (Zeitschrift für praktische Geologie, 1936, vol. 44, Oct., pp. 156–163 : Stahl und Eisen, 1937, vol. 57, Oct. 21, pp. 1202–1203). The geology, distribution, and chemistry of the ore deposits in Finland are reviewed. Nickel and iron ores are referred to.

The Graphite Resources of Lower Austria. A. Reifmüller. (Montanistische Rundschau, 1937, vol. 29, Nov. 16). The author briefly discusses the geology, exploitation and chemical and physical properties of graphite deposits in Lower Austria. The applications of the material to foundry work are noted, and the method of working up the raw material is briefly outlined.

Geology and Mineral Resources of the Western Part of the Arkansas Coal Field. T. A. Hendricks and B. Parks. (United States Geological Survey, 1937, Bulletin No. 847–E). The western part of the Arkansas coalfield covers an area of about 1,100 sq. miles. The most valuable mineral resources of the area are coal and natural gas. The coal is low-volatile bituminous, and is an excellent steam and domestic fuel.

Geology and Mineral Resources of North-Central Chouteau, Western Hill and Eastern Liberty Counties, Montana. W. G. Pierce and C. B. Hunt. (United States Geological Survey, 1937, Bulletin No. 847–F). The coal in this area is of sub-bituminous rank and is present in lenticular beds, generally less than 3 ft. thick. In general the coal is of poor quality.

Geology and Fuel Resources of the Southern Part of the Oklahoma Coal Field. Part 1. The McAlester District Pittsburg, Atoka, and Latimer Counties. T. A. Hendricks. (United States Geological Survey, 1937, Bulletin No. 874–A). The coal deposits of this district are by far the most valuable of the mineral resources. The coal is bituminous and is of good steam and domestic quality. Most of the mining has been confined to two coal-beds, the Lower Hartshorne and the McAlester.

Geology and Mineral Resources of the Baker Quadrangle, Oregon. J. Gilluly. (United States Geological Survey, 1937, Bulletin No. 879). The mineral resources of the area described include deposits of copper, manganese, tungsten and coal.

Molybdenum in Morocco and the World Market for this Metal. (Bulletin Économique du Maroc, Jan., 1937 : Génie Civil, 1937, vol. 111, Aug. 7, pp. 134–135). A brief note on the deposits of molybdenum in the United States of America, Mexico, Norway and Morocco (the Azgour deposit); the production figures for these countries for 1934 are also given.

Titanium, its Industrial and Metallurgical Value and the Possibility of its Discovery in Poland. I. Feszczenko-Czopiwski and St. Jaskólski. (Prace Badawcze Huty Baildon, 1937, No. 2, June, pp. 1–16). The authors have examined the mineralogy, geology, distribution and chemistry of the titanium-bearing minerals, including ilmenite, rutile, titanite, perowskite, and titano-magnetite, particularly in Sweden and Norway, but also in North and South America, India, Africa (Senegal and Sierra Leone), Portugal and some other European countries. Possible Polish resources are briefly discussed. The chemical and physical properties of titanium metal are briefly considered and its compounds noted, particularly the properties of carbides and nitrides; the reactions occurring during the reduction of titaniferous iron ores and the titaniferous pig produced are discussed with appropriate analyses, and special uses and alloys of the metal are examined in some detail. Methods of preparing pure titanium by the aluminothermic process and by reduction of the tetrachloride with sodium hydride are given. (In Polish).

Iron-Ore Resources Outside Europe. (Metallwirtschaft, 1937, vol. 16, Aug. 27, pp. 865–866). The iron-ore resources and production of Russia (Asiatic), China, Japan, Africa, India, Canada, the United States of America, Cuba, South America and Australia are discussed.

The Strategical Significance of Metals in the Economics of Defence. H. Bauer. (Metallwirtschaft, 1937, vol. 16, Oct. 15, pp. 1071–1076). The author presents a critical summary of world resources of metals, including metals of the iron group and those of importance in the manufacture of alloy steels. The strategical vulnerability of such resources to blockade in times of war is considered and the relative distribution of important metals is examined in the light of war-time conditions.

ORES—MINING AND TREATMENT

The Recent Development of Ore Mining in Bolivia. (Metallwirtschaft, 1937, vol. 16, Aug. 6, pp. 785–786). A review of the economics of ore mining in Bolivia. Tungsten is included among the metals dealt with.

Iron Mining in Muscoda No. 6. E. M. Ball and A. W. Beck. (Engineering and Mining Journal, 1937, vol. 138, Sept., pp. 29–34, 37; Oct., pp. 35–39). A detailed account is presented of the development, production and equipment of the Muscoda No. 6 mine of the Tennessee Coal, Iron and Railroad Company. The mine is situated near Birmingham, Alabama.

Ore-Bridge Design has Novel Features. (Blast Furnace and Steel Plant, 1937, vol. 25, Sept., pp. 998–999). A detailed account is presented of the structure and driving mechanism of a 20-ton travelling crane with a span of 523·5 ft., recently erected at the South Works of the Carnegie-Illinois Steel Corporation. Energy is provided for all driving units by electric motors.

Researches on the Conversion of the Nickel Content in Various German Nickel Ores and Minerals into a Water-Soluble Form. V. Tafel and G. Lampe. (Metallwirtschaft, 1937, vol. 16, Oct. 8, pp. 1038–1041). Experiments on the roasting of various nickel-containing minerals are described in which, by treatment of the ore at various temperatures with air/sulphur-dioxide/oxygen or sulphur-trioxide/sodium-chloride mixtures, the nickel content is converted to a water-soluble form. Detailed tabular data are presented.

REFRACTORY MATERIALS

(Continued from pp. 1 A–3 A)

The Application of Pressed Dolomite Refractories in the Open-Hearth Furnace. J. Sittard. (Stahl und Eisen, 1937, vol. 57, Nov. 18, pp. 1305–1306). Experiments are described on the utilisation of dolomite bricks as a lining for the back wall of an open-hearth furnace. Dolomite ground to a grain size of 1–2 mm. was well mixed with about 4% of tar and pressed at 2000 atm. The lining was examined after the furnace had produced 25,000 tons of steel and was found to be in good condition; it had sintered to a very compact mass, which, however, crumbled to dust within ten days after its removal from the furnace; for this reason it is concluded that sintering the lining material before placing in position is a needlessly expensive operation.

Acceptance and Applicability of Fireclay Bricks. R. Rasch. (Glückauf, 1937, vol. 73, Nov. 13, pp. 1033–1037). The author emphasises the desirability of specifying definite determinable qualities when purchasing refractory materials, in place of purchase based on the materials satisfying some arbitrary standard which cannot be interpreted in actual figures. Poor bonding is due to insufficient treatment of the clay, but cracked bonding clay does not affect the quality of the brick, since it is caused by the addition of insufficient lean clay and results in greater resistance to thermal shock. Brittle, crumbling bricks should be avoided; the formation of layers is caused by the inclusion of air during manufacture and is very detrimental. Waviness is due to demulsification of the clay during the manufacture of the brick and must be distinguished from swelling caused by the evolution of entrapped air. Folds caused by oil or water show in the burnt brick and can seriously affect the stability of the refractory; the numerous cracks formed during drying and firing should never be disguised by colouring or surface-washing, as such treatment hinders the detection of faults. Material to be subjected to chemical action and mechanical stressing requires particular attention.

Panel Spalling Tests on Insulating Brick and Insulating Fire Brick. W. R. Kerr. (Bulletin of the American Ceramic Society, 1937, vol. 16, Aug., pp. 322–328). The author describes the furnace used and the method of preparing test panels for the spalling test. Preheat periods of 24 hr. at various temperatures were used in all tests, and spalling tests included 10 cycles of heating and cooling with air-blast at room temperature supplied at the rate of 1400 cu. ft. per min. The first heating indicates whether the material will withstand the required temperature and promotes any structural changes which may occur. Mechanical strength and non-vitrified

structure are held, in conjunction with the absence of marked reducing conditions in use, to determine spalling resistance. The chemical constitution of the brick is said to be of less importance, for any definite temperature, than the physical constitution.

Measurement of the Thermal Conductivity of Insulating Materials. "Touchau" Method. P. Vernotte. (Chaleur et Industrie, 1937, vol. 18, Aug., pp. 331–339). A detailed mathematical treatment of the problems connected with the determination of the thermal conductivity of thermal insulators by the "contact" method is presented. It is pointed out that the contact method is applicable to the determination of the thermal conductivity not only of test-pieces, which may give results varying from those characteristic of the bulk of the material from which they are taken, but also of the material *en masse*, assuming this to be of uniform structure.

FUEL

(Continued from pp. 4 A–7 A)

The Influence of the Economics of Energy on the Location of Industry. G. Kniehase. (Dissertation, Technische Hochschule zu Breslau, 1937). The author presents a detailed critical review of the development of modern industry in relation to the parallel development of energy resources, and determines the influence of the site of the latter on the location and progress of the former. The iron and coal industries are dealt with, together with those industries associated with the manipulation of semi-finished steel and iron.

The Influence of the Mixing Process on the Combustion of Gas and Air in Furnaces. Parts III.C. and IV. K. Rummel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 163–181; Nov., pp. 215–224). The conclusion to a previous series of articles (*see* Journ. I. and S.I., 1937, No. II., p. 255 A). In Part III.C., the author describes his final investigations into the aerodynamics of the combustion of gas and air in the open-hearth furnace, employing special experimental models; the final experiments concern the results obtained with a specially designed burner attached to a model coke-oven-gas-fired acid open-hearth furnace. Part IV. is devoted to a description of the application of the theory evolved from experimental models to actual open-hearth furnaces. It is shown that the results obtained on such models may be reproduced in practice.

Laboratory Investigations on the Combustibility of German Coal Dust. A. Simon. (Dissertation, Technische Hochschule zu Breslau, 1937). The author describes experimental work carried out to verify on coal dusts of German origin the validity of the relationship between the particle size of the dust and its inflammability as determined by Godbert and Greenwald on British and American coals. Certain irregularities were observed with German coals. The results are examined mathematically, and the inflammability equation of Godbert and Greenwald is replaced by another of wider applicability which permits of the interpretation of the results obtained on German coals.

Hilt's Law and the Rank of Coal. J. Roberts. (Colliery Engineering, 1937, vol. 14, Aug., pp. 275–278). The author discusses the interpretation of the so-called Hilt's law relating the volatile content of coal to the depth at which it originally occurred. Reference is made to the effects of folding and to deviations from the law. The need of data other than those dealing with analysis only is stressed. Tabular data are presented.

The Composition and Use of Iowa Coals. H. L. Olin. (Iowa Geological Survey, 1936, Technical Paper No. 3: Fuel in Science

and Practice, 1937, vol. 16, July, pp. 192–203; Aug., pp. 231–241; Sept., pp. 256–266; Oct., pp. 304–309). The author presents a detailed study of Iowa coals; physical and chemical properties are considered, together with factors of industrial importance such as washability and storage and carbonisation characteristics.

The Determination of the Particle Characteristics and Surfaces of Pulverised Products Demonstrated on Rye Flour. H. Sauer. (Dissertation, Technische Hochschule zu Breslau, 1937: Kolloid Zeitschrift, 1937, vol. 79). An apparatus is described, operating on the principle of sedimentation analysis, by which the fineness of powders may be rapidly determined; the concentration is measured optically. The apparatus may be employed on all coarse disperse systems amenable to Stokes' law and in which the light-absorption is independent of the particle size. The adsorption method proved useless for the determination of the surface; the reflection method of Witte yielded results in agreement with those deduced from sedimentation analyses.

Fundamental Processes in the Pulverising of Brittle Materials. A. Smekal. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Nov. 13, pp. 1321–1326). The author discusses the physical bases of pulverising processes effective for brittle and semi-plastic materials (coal and quartz are cited *inter alia*). The technical aspects of fine, medium and coarse pulverising are examined, data being presented for ball-milling, tumbling and roll-crushing. The low mechanical efficiency of these processes is stressed, and the sources of energy loss are enumerated. The author considers that the value of mechanical processes lies in their being able to handle large quantities of material.

By-Product Coking Plant at Cleveland Ironworks. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Aug., pp. 120–132; Sept., pp. 138–145). (*See* Journ. I. and S.I., 1937, No. II., p. 167 A).

Thermo-Technical Considerations Concerning the Coking Process. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Nov. 6, pp. 1315–1316). A summary is presented of investigations on the thermal aspects of the coking process carried out by P. Schläpfer and G. Rohonezi which were described in detail in Technische Hochschule in Zürich, 1936, Report No. 102, pp. 1–22. The research was undertaken to determine the optimum conditions for the heating of the carbonising chamber, and to investigate the processes occurring in the coke-oven and in the gas retorts.

Low-Temperature Carbonisation. (Colliery Guardian, 1937, vol. 155, Aug. 27, pp. 373–377). Operating and output data are presented respecting the experimental plant operated by Catalysts, Ltd., for the low-temperature carbonisation of a mixture of coal and oil. Reference is made to a proprietary substance "Fenilic" employed in the heating circuit; no indication is given, however, of its composition. Full working drawings are given of the plant.

The Influence of Ash on the Quality of Metallurgical Cokes. Bongarçon. (Revue de l'Industrie Minérale, Mémoires, 1937, No. 402, Oct. 15, pp. 477–487). From a study of a series of metallurgical cokes with ash contents ranging from 12 to more than 20%, the author concludes that the mechanical properties of a coke are independent of the ash content, hence the mechanical properties may be controlled independently of this factor. In this way high-quality cokes may be prepared from rich coals and the value of such coke for smelting purposes increased.

Producer Gas from Low-Temperature Coke from Lignites. H. Wohlschläger. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Nov. 6, pp. 1299–1304). The results of investigations on the utilisation of the recently developed massive coke made from lignite for producer-gas manufacture are described. The production of gas for power and heating is considered. Data are presented in tabular form.

Welded Klonne Waterless Gasholder. (Engineering, 1937, vol. 144, Oct. 29, pp. 492–493). Structural details are presented regarding the waterless gasholder in the course of erection at the Dagenham plant of the Ford Motor Co.

Carburetting of Coke-Oven Gas with Pulverised Low-Grade Brown Coal for Heating Acid Open-Hearth Furnaces. E. Wulffert. (Stahl und Eisen, 1937, vol. 57, Oct. 14, pp. 1165–1171; Oct. 21, pp. 1195–1201). The essential features of plant for carburetting the coke-oven gas supply to an acid open-hearth furnace with pulverised low-grade coal are described, and induction by compressed air is shown to be the most satisfactory method of introducing the powder. The influence of carburetting on combustion is considered. It was determined that the heating capacity of carburetted coke-oven gas is strongly controlled by the luminosity of the flame and by the combustion velocity of the gas mixture. The durability of the checkerwork was found to be adversely affected by slag and by dust deposition, but this difficulty could be partially solved by structural modifications. The best results were obtained with an addition of 0·2 kg. of pulverised coal per cubic metre of gas; decreased consumption of ferromanganese and less oxidation of alloying constituents were demonstrated, together with a greater heat efficiency. Improved operating conditions and decreased fuel costs resulted from the use of the carburetted gas, and economies were effected despite the increased cleaning charges and more frequent repairing of the checkerwork required.

PRODUCTION OF IRON

(Continued from pp. 8 A–10 A)

Offsetting Increased Labour Cost in Southern Blast-Furnace Operation. J. M. Hassler. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 854: Metals Technology, 1937, vol. 4, Oct. No. 7). The author presents a detailed study of the economical status of pig-iron production in the Southern States of the United States of America, and, in particular, in the Birmingham district. The review includes a study of the causes of the decreased iron business in the Southern States, the increased labour costs, the industrial development of the district without a corresponding increase in the local demand for iron, increased freight charges, and the depletion of the better grades of ore and coal. Improvements to offset increased cost are next considered; these include the sintering of flue dust, utilisation of slag in the form of special aggregates for concrete, improved blast-furnace design, improved qualities of coke, and improved qualities of pig iron. Graphical and tabular data are presented.

Raw Materials in the German Steel Industry. (Iron and Coal Trades Review, 1937, vol. 135, Oct. 22, pp. 669–670). An abridged translation into English of an article by P. Reichardt which appeared originally in Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1104–1109. (*See* p. 10 A).

FOUNDRY PRACTICE

(Continued from pp. 11 A–13 A)

Choice of Plant in a Jobbing Foundry. A. Sisson. (La Fonte : Foundry Trade Journal, 1937, vol. 57, Oct. 7, pp. 285–288). After reviewing the evolution of machine moulding, the author passes on to a consideration of sand treatment and melting equipment, moulding machines, moulding boxes (aluminium boxes are referred to), the layout of the moulding and casting shops, costing and foundry management.

Loam Moulding of a 5¾-Ton Pot. W. J. Grose. (Institute of British Foundrymen : Foundry Trade Journal, 1937, vol. 57, Oct. 7, p. 277). Brief particulars are given of the operations involved in the loam moulding of a large pot.

A Note on Coring a 15-ft. Roller with a 16-in. dia. Core. W. J. Grose. (Institute of British Foundrymen : Foundry Trade Journal, 1937, vol. 57, Oct. 7, pp. 277–278).

Note on Piston Rings. (Arts et Métiers, 1937, vol. 91, Oct., pp. 217–225). The design, casting, machining and fitting of piston rings are discussed. Cast-iron rings are referred to, of the following composition : Total carbon 3·5 to 3·8%, graphite 2·8 to 3·3%, silicon 2·5 to 2·8%, manganese 0·5 to 0·8%, sulphur 0·04 to 0·06%, phosphorus 0·1 to 0·4%.

The Formation of the Casting Skin on Grey Cast Iron and its Influence on the Quality of this Material. J. Babrowski. (Dissertation, Technische Hochschule zu Breslau, 1937). The author discusses the chemistry and metallography of the casting skin on grey iron. The importance of the mould conditions and casting conditions in controlling the nature of the skin produced is examined, and the effect of the composition of the iron on the type of skin formed is also discussed. The skin has no marked effect on the tensile properties and normally but little effect on bend-test results. The hardness and impact values are normally unaffected. The machinability of the casting and its resistance to deformation are decreased by the skin.

PRODUCTION OF STEEL

(Continued from pp. 14 A–15 A)

Russia Answers America's Open-Hearth Queries. R. Vaill. (Iron Age, 1937, vol. 140, Sept. 16, pp. 34–39). The author compares and contrasts American and Russian open-hearth practice. According to the author, the former aims at lower production costs, while the latter aims at greater output almost irrespective of cost.

Open-Hearth Process and its Influence on the Quality of Medium-Carbon Steel. V. P. Remin. (Katshestvennaia Stal, 1937, No. 3, pp. 7–21). The author has made a close survey of eighteen heats of open-hearth steel, twelve of which were basic and six acid. Samples of metal and slag were taken during the course of melting, and the final products were investigated from the points of view of oxygen content, grain size and non-metallic inclusions. A number of recommendations are given as to the best conditions for carrying out the process. The author deals in detail with the influence of oxygen, deoxidation by aluminium and the problem of inclusions. (In Russian).

Investigations on the Reactions in Basic Open-Hearth Slags During the Melting Cycle, with Particular Reference to the Behaviour of Lime. G. Prieur. (Dissertation, Technische Hochschule zu Breslau, 1937). The free calcium oxide which appears as a new phase in basic open-hearth slags was determined quantitatively by the method of Diepschlag and Matting. The concentration and process of solution of lime in the slag were followed and its equilibrium conditions determined. The influence of the concentration of slag-forming elements on the course of the reactions in the bath was also examined. Data are presented in tabular and graphical form.

Origin of the Duplex Process for Steel at Neuburg in Styria. P. Eyermann. (Montanistische Rundschau, 1937, vol. 29, Oct. 16, pp. 1–4; Nov. 16, pp. 1–6). The author presents evidence from earlier literature to demonstrate his contention that the duplex process for steel making originated not in the United States of America, as is commonly stated and claimed, but in Styria.

Details of a Heat of Stainless Steel Produced in the Electric Furnace. (Steel, 1937, vol. 101, Sept. 27, pp. 54–57). After a brief reference to the peculiar advantages and importance of electric-furnace melting and to the construction and operation of such a furnace, the record of a heat of 18/8 stainless steel is presented, from the moment of repairing the furnace bottom to tapping. The record covers a period of 6½ hr., and is divided into nineteen sections, each covering a definite stage in the progress of the heat.

Electromagnetic Control of the Arc in the Steel Melting Electric Furnace of the "Electrostal" Works. S. I. Gershman and B. S. Vaganov. (Katshestvennaia Stal, 1937, No. 2, pp. 48–51). The paper contains a discussion of an experiment made during 1935–36 by the Electrostal Works on the automatic electromagnetic control of an arc furnace. (In Russian).

Slag Viscosity Control. C. H. Herty. (Blast Furnace and Steel Plant, 1937, vol. 25, Sept., pp. 1000–1001). The control of the composition and the viscosity of basic open-hearth slag is facilitated by the Viscontrol method developed by the Bethlehem Steel Company. The uniform slag obtained has a favourable influence on the ductility, heat treatment, ageing and impact strength of the steel. The method enables the iron-oxide content of the slag, its viscosity and its basicity, to be determined and adjusted at any stage in the process; corrective additions are not required at the end of the refining period. Since a very material control is exercised on the oxidation of the melt, the control is also extended to a large extent to the aluminium added in the ladle, hence grain-size control is greatly facilitated. The instrument in question consists of a steel block drilled with a ¼-in. hole down which the slag is run, the distance travelled being a measure of its viscosity. The value obtained is correlated with the slag and metal analyses, the results being referred to a chart showing the basic or acid additions required to give optimum properties.

Slag Systems. R. Hay, A. B. McIntosh, J. R. Rait and J. White. (Journal of the West of Scotland Iron and Steel Institute, 1937, vol. 44, Mar., pp. 85–89). The authors discuss the technique and results of investigations on the ferrous-oxide/alumina system, the ferrous-oxide/manganous-oxide/alumina system, the ferric oxide/calcium-oxide system, the ferric-oxide/silica system and the ferric-oxide/calcium-oxide/silica system. The apparatus employed for preparing the slag melts is described, and also the physical properties of the melts and their crystallographic characteristics. A detailed discussion on the determination of the viscosity of the systems by the rotating-cylinder method is presented.

Proposals in Connection with Phosphate Slags. G. Trömel. (Stahl und Eisen, 1937, vol. 57, Oct. 28, pp. 1213–1216). The author discusses the relationship between steel output and fertiliser output in the manufacture of steel by the basic process. The significance of fertilisers in agriculture and problems in connection with the provision of phosphates for German agriculture in particular are considered, together with the importance of basic-slag meal in so far as tariff charges are concerned. Proposals regarding the manufacture of the meal are examined. Methods of reducing losses in iron and manganese by concentrating the basic slag are discussed. The development of a phosphate fertiliser to replace basic slag is suggested and discussed as a means of rendering agriculture independent of the production of steel for its supply of phosphates.

FORGING, STAMPING AND DRAWING

Early Hammers as Monuments of Technical Culture. (Stahl und Eisen, 1937, vol. 57, Nov. 18, p. 1309). A brief description is given of the history, construction and mode of operation of a tail-helve at Deilbachtal (Essen) and of a tilt-hammer at Nachtigallental (Essen).

Hydraulically-Operated Opposed-Action Hammers. E. Müller. (Stahl und Eisen, 1937, vol. 57, Nov. 18, pp. 1307–1308). The development and essential features of the opposed-action hammer for drop-forging are briefly discussed, and its advantages over the drop hammer considered. An account is then given of a recently-designed hammer of this type which, unlike earlier designs that were operated by steam or compressed air, is actuated hydraulically.

Developments in Cold Heading at General Electric. A. R. Ryan. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 601–607). After discussing briefly the advantages and development of the manufacture of screws and bolts by cold heading, the author considers modern cold-heading plant and plant layout at the Schenectady works of the General Electric Company, describes in particular the heat-treating of the headed components and the equipment for carrying it out, and indicates future developments in connection with increased production and improved quality.

The Forging of Crankshafts. M. Blanc. (Arts et Métiers, 1937, vol. 91, Aug., pp. 187–191). The author gives brief details of the procedure in forging crankshafts of various designs.

Cold-Drawn Bars. D. W. McDowell. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 609–612). The author describes the essentials of the cold-drawing process applied to bars and sections, indicates the special physical and mechanical properties of such material and discusses the microstructure in relation to subsequent machining, concluding with a comment on the production of special shapes.

The Influence of the Electrolytic Pickling Process on the Deep-Drawing Qualities of Steel Sheet. W. Baukloh and K. Gehlen. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Nov., pp. 253–258). After discussing the theories concerning the adsorption of hydrogen from liquids by steel sheet, the authors develop a theory concerning the influence of surface-finish and of inhibitors on the diffusion of hydrogen into steel. A series of electrolytic pickling tests was carried out to determine the influence of the following factors on the deep-drawing qualities of a 0·09% carbon steel: Sulphuric-acid concentration, temperature, time of pickling, current density, the presence of additions of selenium, arsenic, sulphur, phosphorus, platinum, tin and zinc. Arsenic, sulphur and phosphorus depress the diffusibility of hydrogen into steel very considerably, and hence exhibit a marked influence on the deep-drawing qualities of

the pickled metal. The results of plain acid pickling and of the electrolytic pickling are compared, special reference being made to the anomalous behaviour of arsenic.

The Manufacture of Fourdrinier Wires. H. E. Brown. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 592–598). The use, manufacture, and mechanical and corrosion testing of Fourdrinier wires are discussed. Particular attention is paid to the drawing operations involved and to the weaving of the mesh. The finished belt is subjected to intensive flexing tests designed to simulate operating conditions. Various copper and nickel alloys and stainless steels of different types are employed for manufacturing Fourdrinier wires which are to be subjected in use to highly corrosive conditions.

Lime in the Wire Industry. D. E. Washburn. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 572–575). The author discusses the methods of manufacturing lime in shaft and rotary kilns, and examines the relative merits of each method as a means of producing a lime suitable for use in wire-drawing. The physical properties of the lime used for this purpose are considered, and some reference is made to the chemical requirements sometimes specified.

On the Oxidation of Steel Wire and its Influence on Subsequent Operations. F. Körber and W. Asbeck. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 12, pp. 161–185). After a general discussion on the oxidation processes occurring in steel during rolling, the authors examine in detail the oxidation taking place during the manufacture of wire. Difficulties in redrawing, pickling and other operations on oxidised wire are discussed with respect to a continuous mill; the plant layout for both this type of mill and a semi-continuous mill is described. A coil of wire from each mill was investigated to determine the losses by oxidation and pickling. The favourable influence of a longer cooling section beyond the finishing mill in decreasing the oxidation and improving the pickling properties is discussed, and a large-scale investigation in a wire mill is described.

The Oxidation of Wire and its Influence on Subsequent Working. W. Asbeck. (Stahl und Eisen, 1937, vol. 57, Oct. 21, pp. 1189–1195; Oct. 28, pp. 1216–1225; Nov. 4, pp. 1249–1255). A slightly abridged version is presented of the paper dealt with in the preceding abstract.

ROLLING-MILL PRACTICE

(Continued from p. 16 A)

Roughing of Rolls and the Properties of Rolled Metal. I. K. Anziferov. (Katshestvennaia Stal, 1937, No. 2, pp. 24–26). The author describes the different methods of roughing the surface of the rolls (in order to obtain a better grip) which are still used in numerous mills, and the bad effects which they have on the quality of the rolled metal. (In Russian).

Grinding Machines for Rolls and Cylinders. E. Lüngen. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Oct. 9, pp. 1197–1198). A brief account is presented of the evolution of the modern roll-grinding machine, and of certain modern types as exemplified by those produced by the firm of C. G. Haubold, A.-G., Chemnitz.

Concerning Roll Bearings. W. Rohn. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 261–262). The author describes experiments in which the bronze bearings of a cold strip mill were replaced by needle bearings running direct on the unhardened neck of the roll and in a thin hardened race. For any given material the reduction per pass could be increased to such a degree that the number of passes required was lessened by a third in comparison to that required when bronze bearings were employed; the energy consumed decreased by about a half. The construction of the bearing is described.

Protected Lubrication for Rolling Mill Machinery. (Lubrication: Sheet Metal Industries, 1937, vol. 11, Oct., pp. 886–888; Nov., pp. 983–984). The development of lubricating systems for rolling-mill plant is considered with particular reference to centralised control of the lubricating equipment. Grease-gun lubrication and the circulation of oils of relatively low viscosity through gears and bearings in oil-tight housings are discussed. The effects of water and metallic particles in the oil supply are examined, and the importance of working the lubricating system in conjunction with a conditioning plant is stressed. Compressed-air-operated lubricating systems for gearing are also referred to.

Rolling-Mill Equipment for the Jugoslavian Iron Industry at Zenica. C. Hoffmann. (Stahl und Eisen, 1937, vol. 57, Oct. 14, pp. 1171–1173). An account is given of the construction, layout and operation of the plant installed at Zenica for rolling bars, plate and heavy- and light-gauge sheet.

Some Problems in the Production of Low-Carbon Sheets in Non-Continuous Mills. M. L. Samuels and A. Boyles. (American Society for Metals, Oct., 1937, Preprint No. 28). The failure of sheets in cold-forming is discussed from the standpoint of grain

size. Examples are shown of failures due to very fine grain as well as to coarse grain. Among the factors influencing the degree of strain produced by rolling, two are pointed out in particular: (1) The effect of segregation in the core of rimmed ingots; (2) the effect of the grain size of the sheet bar previous to rolling into sheets. The view is advanced that phosphorus, by increasing the stiffness of the metal at finishing-mill temperatures, increases the degree of strain, and consequently produces a finer grain size after box-annealing. Fine-grained cores in sheets from the upper part of the ingot are attributed in part to this cause. Experiments are described illustrating the effect of the grain size of the sheet bar before rolling on the grain size of the sheet after box-annealing. It is thought that a coarse-grained sheet bar is strained less in rolling than one having a fine grain. Irregularities in structure in the finished sheet may sometimes be traced to exaggerated grain growth on the surface of sheet bars due to their having been stacked hot at the bar mill.

Trends Affecting the Future of Steel Production. J. L. Young. (Steel, 1937, vol. 101, Sept. 20, pp. 108–109, 114). The development of rolling-mill plant is discussed with particular reference to strip mills of the continuous and semi-continuous types.

Distribution Lines, Control and Drives Placed in Tunnels at New Wire Mill. (Steel, 1937, vol. 101, Oct. 4, pp. 63–66). Main distribution circuits, the controls and a number of drives are housed in tunnels formed by specially adapted foundations at the South Chicago Wire Mill of the Republic Steel Corporation. In the account presented, special attention is paid to the design and means of supporting bus bars and to the insulation of feeder circuits, which if carrying more than 600 V. are in steel conduit embedded in concrete. A mercury-arc rectifier is employed to provide direct current. Details are also given of the motor equipment and design.

Electric Control Gear for the Ebbw Vale Steel Works. (Engineering, 1937, vol. 144, Oct. 29, pp. 482–483). Constructional and operating data are presented regarding the equipment built by the Igranic Electric Co., Ltd., for controlling a number of the auxiliary motors at the Ebbw Vale Iron and Steel Works of Messrs. Richard Thomas and Co., Ltd.

PYROMETRY

Contribution on the Choice of Tube Materials for Pyrometer and other Protective Tubes. (Internationale Röhrenindustrie, 1937, vol. 2, June, pp. 7–8). A very short discussion of materials for the production of protective tubes for pyrometers, &c., leading up to a reference to "Nichrotherm" and "Ferrotherm," two heat-resisting alloys made for such purposes by Krupps.

Automatic Control Eliminates Danger of Burning Out Open-Hearth Roofs. A. V. Leun. (Steel, 1937, vol. 101, Aug. 16, pp. 61–63). A description is given of the radiation and thermo-electric pyrometers employed for controlling the roof temperature of open-hearth furnaces. Details of mounting and calibration are presented.

Comparative Temperature Measurements on Melts of Pig Iron, Cast Iron and Steel. K. Guthmann. (Stahl und Eisen, 1937, vol. 57, Nov. 4, pp. 1245–1248; Nov. 11, pp. 1269–1279). Colour-pyrometry provides a direct means of determining the true temperature of molten iron and steel, of metallurgical melting and heating furnaces and of flames. Measurements taken with a colour-pyrometer show that the emissivity of a melt can vary not only from point to point, but also with respect to time and according to the existing metallurgical and operating conditions obtaining, particularly with regard to the manganese content. In regard to temperature corrections, the value for the temperature of the melt is of the highest importance; the carbon content has little effect, but the presence of easily oxidisable alloy constituents may lead to a considerable increase in the radiating capacity of the melt. The existence of critical temperature ranges requires notice, especially in the case of molten pig iron, when these are connected with the formation or decomposition of oxides. It is probable that above certain temperatures the metal-oxygen compounds are no longer stable, owing to the increased reducing powers of the carbon present; the emissivity is known to diminish under such conditions to about 0·2, probably for this reason. The true temperatures of steel and iron melts on tapping and casting vary only within narrow limits, according to the type of metal being poured and the operating conditions; for steel the mean temperature before and during tapping is approximately 1700° C., and for casting it is about 1615° C.; with increasing carbon contents the freezing temperatures and hence the casting temperatures will be correspondingly lower. Similarly the casting temperature for alloy steels will also be lower. Owing to the impossibility of correcting the values obtained with the disappearing-filament pyrometer, since every melt possesses a different emissivity, the true values should be determined in the first place. Data are presented in the article in graphical and tabular form.

HEAT TREATMENT

(Continued from pp. 17 A–19 A)

Case-Hardening of 14% Chromium Steels. E. Widawski. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 195–198). Two 14% chromium steels with carbon contents of 0·12% and 0·45%, respectively, were carburised under various conditions. The carbon content of the skin in specimens case-hardened at above 1000° C. reached a maximum of 3·0%. With temperatures above 950° C., the penetration increased rapidly, whilst in the range up to 950° C. carbon absorption soon ceased; in this last temperature range the duration of heating had little effect on either the depth or the carbon content of the case. Carburisation above 1000° C. leads to the formation of a coarse network of carbide, owing, apparently, to the precipitation of chromium carbide at the grain boundaries after saturation of the γ solid solution with carbon. The greatest hardness was obtained by quenching the fully carburised steel from 830° C.; more violent quenching resulted in decreased hardness owing to the increased retention of austenite. The retention of hardness on tempering the specimens quenched from low temperatures was in general only moderate.

Flame Hardening. (Steel, 1937, vol. 101, Sept. 27, pp. 34–36). The advantages of flame hardening are briefly discussed and the four methods of conducting the operation noted, namely, the stationary method involving no movement of flame or work, the progressive method in which blowpipe and work move with respect to each other, spinning methods in which the work is rotated before the flame and quenched during rotation, and combination methods involving the simultaneous use of two or more of these procedures. Some suggestions are made as to the satisfactory setting up of the blowpipe and quenching arrangements.

On the Oxidation of Metals and Alloys. E. Scheil. (Zeitschrift für Metallkunde, 1937, vol. 29, July, pp. 209–214). The progressive oxidation of metals depends on the diffusion of metallic ions through the oxide layer first formed; a new lattice is therefore formed on the surface of the layer. If scaling occurs, exposure of the oxide film in contact with the metal surface may take place; periodic scaling may permit linear progress of the oxidation with respect to time. In alloys the oxides of the components form approximately in the order of their heats of formation. Regarding the arrangement of the oxides in the film, the alloy additions usually concentrate at the oxide-metal interface regardless of whether they are more noble or less noble than the basis metal. The conditions necessary for the formation of coatings which will protect alloys from progressive oxidation are discussed. Among the steels referred to are those containing up to 8·5% of aluminium.

The Effect of Grain Size on the Oxidation of a Low-Carbon Steel. C. A. Siebert and C. Upthegrove. (American Society for Metals, Oct., 1937, Preprint No. 12). The authors deal with the effect of grain size on the oxidation of low-carbon steels in the temperature range 1700° to 2100° F. It has been found that the fine-grained steels oxidise to a greater extent than coarse-grained steels. The ferrous iron content of the scale formed at any given temperature in this range is higher for the fine-grained steels than for the coarse-grained steels, which results in a greater rate of diffusion and therefore a higher scaling loss.

The Steel Heat-Treatment Department of Messrs. The Darlington Forge, Limited. (Engineering, 1937, vol. 144, Oct. 22, pp. 451–452). The furnaces installed in the new heat-treatment department of Darlington Forge, Ltd., have been specially designed to handle a wide variety of steel castings and forgings. They include a vertical electric furnace, a horizontal bogie electric furnace and five horizontal bogie producer-gas-fired furnaces. Structural and operating data are presented and reference is made to auxiliary equipment.

A Small Pulverised-Fuel-Fired Furnace. L. Kletetschka. (Stahl und Eisen, 1937, vol. 57, Oct. 21, pp. 1203–1205). The author reviews the different types of furnaces commonly employed for the heat treatment of small components and indicates their disadvantages. The construction of a small pulverised-fuel-fired furnace is then described; full operating data are given and the performance of the furnace on different types of small work is noted.

Special Lifting Tackle for Heat-Treatment Equipment. C. Hubert. (Stahl und Eisen, 1937, vol. 57, Nov. 11, pp. 1279–1281). The essential features of lifting tackle for heavy work in the heat-treating shop are discussed, and the structural and operating details of suitable equipment examined. A new type of rapid-lowering device is described, the speed being controlled by the load.

"Double-Treating" Track and Frog Bolts. C. Fassinger. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 613–621). The author compares the mechanical properties of bolts heat-treated by the "time-quench" method and by the normal double treatment. The lack of uniformity in the section of the bolt gives rise to non-uniform mechanical properties after treatment by the first method; this disadvantage is obviated in the second method, which gives impact values about 50% higher than the time quench. Tabular and graphical data are presented.

Heat Treatment of Nuts and Bolts. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 81–82, 94). An account is presented of the manufacture of bolts in carbon and alloy steels at the works of Messrs. A. P. Newall and Co., Ltd., Possilpark, Glasgow. The forming and machining processes, heat treatment and testing are discussed.

Hot Die Steels and Their Heat Treatment. N. A. Pett. (Metals Treatment Society of New South Wales: Australasian Engineer, 1937, vol. 37, Sept. 7, pp. 14–17, 36–38). The author enumerates the processes of drop forging, upset forging, extrusion and die casting, and then passes on to a consideration of the steels employed for the dies. Plain carbon steels, chromium steels, chromium-molybdenum steels, chromium-vanadium steels, nickel-chromium and nickel-chromium-molybdenum steels, low- and high-tungsten chromium-tungsten steels and complex chromium-tungsten steels are dealt with, the heat-treatment processes being considered in detail. Under the heading of die casting the analyses of suitable alloy steels are tabulated in conjunction with the groups of die-casting alloys for which they may be used; casting temperatures are given for these alloys. Steels suitable for extrusion dies are considered together with materials for pads and mandrels; chromium-tungsten steels are referred to. Typical failures and die design are discussed in relation to practice.

Isothermal Annealing of Tool Steel. A. N. Alimov, N. N. Lipchin and N. F. Sivkov. (Katshestvennaia Stal, 1937, No. 2, pp. 37–40). The authors have investigated the possibility of replacing the usual annealing of special steels—(1) 2·34% carbon, 12% chromium; (2) 1·41% nickel, 0·42% molybdenum; (3) 1·20% chromium, 1·70% tungsten; (4) 2·53% chromium, 8·40% molybdenum, 0·33% vanadium; and (5) 3·90% chromium, 17·5% tungsten—which requires about 36 hr., by the much quicker isothermal annealing. They found that by a suitable adjustment of the heating and of the "quenching" temperature, each of these steels could be annealed completely (*i.e.*, to Brinell hardness 220–240) in less than 6 hr. For steel (1), for instance, the method consists in heating to 900° (which requires 8 hr.), keeping this temperature for 1–1·5 hr., cooling quickly (in the opened furnace) to 700° C., and holding at this temperature for 3 hr. For steels (2) and (3), the temperature at which the austenite decomposes most rapidly is 650–660° C., for steels (4) and (5) 720° C. (In Russian).

Thermal Treatment of Spring Strips of Silicon Steel. K. P. Kolchin and I. A. Savinkov. (Katshestvennaia Stal, 1937, No. 2, pp. 27–33). The authors have investigated the influence of the thermal treatment of silicon steel strip (0·68% carbon, 1·72% silicon) on its elastic properties. The treatments carried out were: (1) Isothermal hardening (from 900° to 340° in a lead bath); (2) hardening in steps (quenching at 300–340°, immediate removal from the lead bath and cooling in air); (3) quenching in oil (from 900° to 20° C.). The last method causes distortion of the strip and is not to be recommended. The two other methods give about the same results; method (2) has the advantages of a continuous process. A comparison of the properties of the strip investigated with those of strip made at Sandviken, (which has about the same composition) revealed the possibility of a considerable increase

in elasticity (about 90 bends over a radius of 7·5 mm. instead of 30). It was found that an improvement of this kind can be achieved by annealing the strip after the last rolling, preferably at 650–770° C. (In Russian).

The Heat Treating of a Winner. H. C. Knerr. (Iron Age, 1937, vol. 140, Oct. 14, pp. 67–75). An account is presented of the heat treatment of components in the steel structural work of a racing yacht, and of the mechanical test results obtained on the finished parts. Several grades of nickel-chromium, chromium-vanadium and chromium-molybdenum steels were used.

Graphitisation of Strip Steel. K. P. Kolchin and E. L. Assur. (Katshestvennaia Stal, 1937, No. 3, pp. 35–40). The authors have investigated four strip steels, two, *A* and *B*, made of carbon steel (1% carbon), and two, *C* and *D*, made of silicon steel (1·6 and 1·76% silicon). All of them showed no graphite spots before the thermal treatment. After annealing, the carbon steel *A*, which had a normal structure, still had only very few graphite inclusions, and these appeared first at 680–750° C. Steel *B*, which had an abnormal structure according to the McQuaid-Ehn test, developed a great number of graphite spots even at 600° C. Steel *C*, which contained 0·3% of chromium, did not exhibit graphitisation, whereas steel *D*, without chromium, developed many black spots at 680–750° C. It is thus demonstrated that graphitisation occurs during annealing, and the authors recommend the annealing of steel strip at 680° as rapidly as possible, to avoid this effect. Deformation by cold-working (*e.g.*, rolling) before annealing strongly enhances the danger of graphitisation. (In Russian).

A Hardenability Test for Carburising Steel. W. E. Jominy and A. L. Boegehold. (American Society for Metals, Oct., 1937, Preprint No. 21). The authors describe a test which permits the grading of carburising steels of various compositions and grain sizes according to their relative hardenability. A number of the more common steels were tested and classified by means of this test. The rate of cooling necessary to harden these steels to 600 Vickers Brinell was determined. The limiting section size in which the more common carburising steels can be used to produce a hardness of 600 Vickers is also indicated.

Effect of Carbon on the Hardenability of High Purity Iron-Carbon Alloys. T. G. Digges. (American Society for Metals, Oct., 1937, Preprint No. 3). High-purity iron-carbon alloys, varying in carbon content from 0·23 to 1·21%, were prepared by carburising vacuum-fused electrolytic iron in a hydrogen-benzene mixture. The homogeneity of the alloys was ensured by heating and cooling the carburised bars *in vacuo*. Determinations of the critical cooling rates of the alloys were made by quenching directly from the temperature establishing a constant austenitic grain size with all the carbon in solution. The critical cooling rate was taken as the average cooling rate between 1110° and 930° F. which produced in

the quenched specimen a martensitic structure with nodular troostite (fine pearlite) in amounts estimated to be between 1 and 3%. With constant austenitic grain size and complete solution of the carbon in the austenite, the critical cooling rate decreased continuously with increase in the carbon content of the alloys. The hypereutectoid alloys thus had slower critical cooling rates (greater hardenability) than the alloys of either eutectoid or hypo-eutectoid composition. However, a small change in the carbon content of the lower-carbon alloys had a more marked effect on the critical cooling rate than did a corresponding change in the higher-carbon alloys. The carbon content of the austenite, therefore, had a pronounced influence on the hardenability of the alloys. Full depth of hardening is obtained only when all the carbon is in solution in the austenite. Under similar conditions with respect to austenitic grain size, carbon content, and complete solution of the carbon in the austenite, the high-purity iron-carbon alloy hardened less deeply than do plain carbon steels.

Quantitative Hardenability. J. L. Burns, T. L. Moore and R. S. Archer. (American Society for Metals, Oct., 1937, Preprint No. 5). To determine the hardenability of a steel, two factors should be measured and expressed : (1) The maximum hardness attainable on quenching (referred to as H_{max}), and (2) the " penetration effect." The authors propose the standardisation of a test for hardenability and a method of expressing the results in quantitative but simple terms. Details of the testing procedure are described. The maximum hardness on quenching is shown to depend on the carbon content alone in the case of plain carbon and the common alloy steels. The penetration effect depends chiefly on the chemical composition and on the austenitic grain size. The effects of these factors on the hardenability are indicated in a quantitative manner for a wide range of plain carbon steels. The relationships between mass and penetration are illustrated with respect to three steels quenched in sections from $\frac{3}{4}$ to 3 in. in dia.

Step-Hardening of Chromium-Tungsten-Manganese Tool Steel. A. N. Alimov. (Katshestvennaia Stal, 1937, No. 3, pp. 25–28). The author has investigated the decomposition of the austenite in the carbon-tungsten-manganese steel *ChVG* (1% carbon, 0·32% silicon, 1·07% manganese, 1·04% tungsten, 0·98% chromium), under the conditions of step-hardening. The heating temperature was varied from 790° to 880°, and the temperature of the intermediate bath from 190° to 400°. The investigation included dilatometric, magnetometric, and microstructural observations, as well as measurements of the impact toughness and hardness. The decomposition of austenite follows the laws found for this process in the case of isothermal quenching, *i.e.*, the decomposition has a constant velocity after the end of the " incubation " period. The following thermal treatment is recommended for the tools : Heating to 830° C., cooling in fused salt (270–300° C.), and finally cooling in

air. If cold-working of the tools is required, it must be done during the cooling in air, before the decomposition of the residual austenite. After step-hardening, the steel contains considerable internal stresses and exhibits a correspondingly low impact toughness. The stresses can be removed and the impact resistance increased by annealing at 200° C. (In Russian).

Mechanical Properties of Large Steel Pieces Subjected to a Stepped Heat Treatment. E. S. Tovpencz. (Katshestvennaia Stal, 1937, No. 2, pp. 33–36). The author stresses the fact that laboratory investigations of the results of isothermal quenching and hardening in steps mostly bear on small pieces only. He has investigated the behaviour of cylinders and bars of large size (*e.g.*, hollow cylinders 2500 cm. long, with walls 13 cm. thick) made of chromium-molybdenum-vanadium, chromium-molybdenum, chromium, and chromium-nickel-molybdenum steel. The step-hardening becomes less and less favourable with an increase in the concentration of the components other than iron and with the mass of the piece, because of the impossibility of regulating the temperature so as to obtain the optimum velocity of cooling. For nearly all the samples investigated, the mechanical properties of the pieces hardened in steps were lower than those of the control pieces hardened in the ordinary way. (In Russian).

Influence of Hardening in a Hot Medium and of Repeated Tempering on the Hardness and Red-Heat Stability of High-Speed Steel. S. S. Steinberg. (Katshestvennaia Stal, 1937, No. 3, pp. 22–25). According to the Steinberg and Zjuzin theory (Ural Metallurgy, 1934, No. 1) martensite produced by the quenching of steel is different from that obtained by tempering. The difference is due to the liberation of carbides which occurs during the tempering process before the transformation of the residual austenite into martensite takes place. The "secondary" martensite has better mechanical properties than the "primary"; the author suggests, therefore, that the formation of the latter should be avoided altogether. For this purpose, the usual quenching in cold oil must be replaced by quenching in a hot medium (560–620° C.). The austenite-martensite transformation must be allowed to proceed first after a sufficient "ageing" of the austenite at this temperature, *i.e.*, after the liberation of carbides from the solid solution. To complete the transformation and to deprive the martensite as far as possible of dissolved carbides, repeated tempering is recommended. Practical tests were carried out by the Electrostal Works and by the Cheljabinsk Metallurgical Works. In the first case, steel with 0·7% of carbon, 17·3% of tungsten, 4·13% of chromium and 0·5% of vanadium was investigated. Quenching from 1280° to 560–620° C. produced a metal with much higher red-heat stability than quenching in cold oil. At 560° C. the highest hardness and red-heat stability were obtained by leaving the sample in the bath for 4 hr.; at 620° C. the optimum duration was 20 min. The influence of repeated

tempering was investigated on cutting tools made of *PO* steel (0·76% carbon, 16·65% tungsten, 3·78% chromium, 0·88% vanadium). Cutting tools tempered three times at 560° C. (after quenching at 620°) showed an increase in the maximum cutting velocity of 11% and in the maximum cutting life of 175%. In the second series of experiments, *P* steel (0·8% carbon, 4·65% chromium, 18·4% tungsten, 0·56% vanadium) was investigated, with results of the same character. Magnetic measurements confirmed that repeated tempering leads to a more complete disappearance of the austenite; the author stresses, however, that the most important effect of this treatment is the change in the quality of the martensite, and not in its quantity. (In Russian).

The Mechanism of Steel Hardening and Tempering as Indicated by Coercive Force Measurements. R. S. Dean and C. Y. Clayton. (American Society for Metals, Oct., 1937, Preprint No. 1). To explain the relation between the hardness and coercive force of steels subjected to various treatments, the authors put forward the hypothesis that in the hardening and tempering of steel the following steps take place: (1) The grains break down into blocks, thus forming an internal surface which greatly increases the coercive force. (2) The second phase is precipitated at the internal surface and greatly increases the hardness. (3) The internal surface heals, causing a reduced coercive force. (4) The precipitated phase agglomerates, causing a decreased hardness. The possible uses of coercive force measurement as a shop-control method are suggested.

Alloy-Steel Tool Tempering. R. Saxton. (Wire Industry, 1937, vol. 4, Aug., pp. 435–437). After a discussion of the general principles of hardening and of the objects of heat treatment, the author discusses the theory and practice of high-speed tool-steel hardening and concludes with brief notes on the hardening and quenching heats for some typical high-alloy steels.

Effect of Tempering Quenched Hypereutectoid Steels on the Physical Properties and Microstructure. C. R. Austin and B. S. Norris. (American Society for Metals, Oct., 1937, Preprint No. 2). The authors present a critical review of the literature dealing with the reactions occurring in carbon steels below the eutectoid inversion, and with their effect on the physical properties. The difference in the reaction to tempering of hypereutectoid carbon steels, of similar chemical composition after quenching from 1000° C., is then discussed in terms of electrical resistivity, magnetisation coercive force, Rockwell hardness and microstructure. The profound difference in the behaviour of the steels, particularly with respect to graphitisation at 650° C., is illustrated by data obtained on the physical properties and by metallographic records. Austenitic grain size was also observed to have an influence on the behaviour of the steels during tempering. This factor appears to exert its influence by controlling the nature of the quenched structure, which in turn regulates the manner in which the carbides precipitate and further react during tempering.

WELDING AND CUTTING

(Continued from pp. 20 A–21 A)

Applications of Autogenous Welding in the Foundry. R. Granjon and H. Gerbeaux. (International Foundry Congress, Paris, 1937 : Foundry Trade Journal, 1937, vol. 57, Oct. 7, pp. 283–284). After a brief discussion on the applications of welding technique in the foundry, the authors proceed to a more detailed consideration of the fabrication by welding of foundry equipment and the construction of composite components built up of castings welded together or of rolled sections welded to castings.

Electric Welding. P. J. Risdon. (Electric Welding, 1937, vol. 6, June, pp. 134–155; Aug., pp. 197–210). A general outline of the theory and practice of arc welding. Various types of weld are described, and some account of electrodes is given, together with corrosion and mechanical tests on welds.

Automatic Resistance Welding. H. Landstrom. (Welding Journal, 1937, vol. 16, Oct., pp. 12–14). The author describes the essentials of various electric welding processes and stresses the importance of automatic control. Various types of control mechanism are briefly examined, and the author concludes with an account of gun welding, stressing the feature of automatic control.

Power Supply for Welding. A. S. Douglass and L. W. Clark. (Welding Journal, 1937, vol. 16, Oct., pp. 64–70). The authors present an evaluation of the work done in arc, gas and resistance welding in terms of kilowatt-hours. Resistance-welding loads constitute a special problem and are examined in greater detail; metering, power supply, limitations imposed by the supply system and the most satisfactory method of service, welding machine power factor and plant distribution are each considered under a separate heading. Graphical data are given.

The Heat Effect in Welding. A Review of the Literature to January 1937. W. H. Bruckner. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 53–70). Sufficient data have not yet been accumulated to enable a review to be made of all the factors influencing the heating effect in welding; the following aspects are considered and summarised: The thermal cycle of the welding operation; hardenability; physical properties; remedies for heat effects. In addition, welding tests and some notes on the further investigations required are also presented. Graphical and tabular data are included.

Discussion on Fusion Welding Wrought Iron. B. D. Landes. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 71–72). The author describes and discusses tests carried out in 1935–1936 for the American Bureau of Shipping and Lloyds' Register. The tensile properties and chemical analysis of weld metal deposited

from ordinary coated mild-steel electrodes on to wrought-iron plate were determined, standard specimens being used. The results of the investigation are presented with tabular and graphical data.

Spot-Welding of Low-Alloy Steels. G. S. Mikhalapov. (Welding Journal, 1937, vol. 16, Oct., pp. 59–61). After reviewing the mechanics of the spot-welding process, the author discusses the technique in relation to the modified physical characteristics of low-alloy steels as compared with those of mild carbon steel. The importance of suiting the design of low-alloy steel structures to the peculiarities of the material and to the technique employed for welding it is considered.

Stainless as Applied to Pressure Vessels. J. C. Holmberg. (Welding Journal, 1937, vol. 16, Oct., pp. 44–49). The welding operations carried out on pressure vessels for various purposes in 19% chromium, 9% nickel and 15–16% chromium steels are briefly commented upon, the influence of the special characteristics of the material on the operations being stressed. Among the plant referred to are vessels for nitric and acetic acid, containers for the artificial silk industry, nitriding pots and a fractionating column for fatty acids constructed of niobium-bearing austenitic stainless steel. Heat-treatment processes subsequent to welding are discussed.

Notes on the Manufacture of Steel Sheet for Welding Purposes. A. Regè. (Metallurgia Italiana, 1937, vol. 29, Sept., pp. 457–472). The author discusses the manufacture of large mild-steel sheets designed for such purposes as the fabrication of large-diameter tube by welding. The analysis of the material, casting, reheating and rolling techniques, and welding problems are discussed.

Hydraulic Presses With Continuous Welded Frames. E. Chapman. (Iron Age, 1937, vol. 140, Oct. 21, pp. 36–39). An account is given of the construction and principles underlying the design of an all-welded frame for hydraulic presses developed by Lukenweld Inc., Coatesville, Pa. Presses up to 2100 tons capacity have been built with frames fabricated in this way.

The Influence of the Type of Current on the Quality of Welded Joints. C. Stieler. (Dissertation, Technische Hochschule zu Breslau, 1937). From experimental work on arc welds it is concluded that the price and capital outlay and maintenance costs are lower for a welding transformer than for a rotary converter, but that whilst the output of the former is greater than that of the latter, the power factor is considerably lower unless condensers are employed to improve it. The consumption of the electrodes and losses due to spluttering and burning depend on the type of electrode used; no fundamental difference in these quantities has been detected for either type of current. Alternating-current welding is more dangerous than direct-current welding, since the peak voltage of the former is higher; the direct-current arc is more sensitive to

magnetic disturbances than the alternating arc. Welds made with either type of current are equally good as regards mechanical properties and structure.

Static and Impact Tensile Properties of Some Welds at Ordinary and Low Temperatures. O. H. Henry. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 41–46). Comparison of the static and impact tensile properties of resistance butt, atomic hydrogen and bronze welds in 0·25% carbon steel and gas and arc welds in 18/8 stainless steel show that the static tensile properties do not vary with temperature between + 20° C. and — 80° C. in the same way as the impact tensile properties; neither vary much within this temperature range, and the static tensile properties of two types of oxy-acetylene welds in structural steel are also unaffected if the welds are correctly executed.

Bending-Fatigue Strength of Welded Chromium-Molybdenum Steel Tubes for Aircraft Construction. (Stahl und Eisen, 1937, vol. 57, Nov. 11, pp. 1283–1284). An abstract of a paper by H. Cornelius and F. Bollenrath which appeared originally in Luftfahrt Forschung, 1937, vol. 14, pp. 520–526. The results are presented of an investigation of the mechanical properties, in particular the resistance to fatigue by bending, of thin-walled chromium, molybdenum steel tubes in the plain and butt-welded states. The effects of heat treatment after welding are discussed; both oxy-acetylene and atomic-arc welding are referred to. Tabular and graphical data are presented.

Fatigue Tests of Butt Welds in Structural Plates. W. M. Wilson. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 23–27). Arbitrarily defining the fatigue strength as the maximum stress to which the specimen welds could be subjected for 2×10^6 cycles without failure, the author describes a series of tests carried out on butt welds in $\frac{3}{4}$-in. structural steel plates. The testing machine used and the form of the specimens are both fully discussed. Tabular data are presented from which it is concluded that the unit fatigue strength in carbon steel plates in the as-welded condition is reduced by stress concentration at the edge of the weld due to change of section; the value may be increased by planing off excess weld metal. In addition, the values for specimens welded by means of the automatic carbon arc are somewhat higher than those for welds made by the hand-operated metallic arc. Silicon steel gave values limited to those of the filler metal. Peening the beads and stress-relieving by heat treatment proved to have little effect on the fatigue strength of the welds. The unit fatigue strength of a correctly made butt weld estimated on the gross section was shown to be approximately 88% of the value obtained on a riveted joint in the same plate; this applies to carbon steel and silicon steel.

Tests and Arc Welding in Ship Structure. W. P. Roop. (Welding Journal, 1937, vol. 16, Oct., pp. 15–17). The author discusses and outlines a method of testing electrodes, equipment, and the

material to be welded, and also of testing the skill of the welder, the suitability of different techniques, finished joints, designs of welded structure and finally the completed structure.

Mechanical Cutting in Railroad Work. H. Bass. (Welding Journal, 1937, vol. 16, Oct., pp. 18–21). The author discusses briefly the applications of machine gas-cutting in rolling-stock construction operations and notes the steels which may be manipulated by this means and the effect of the operation on the steel. A description of the machine employed for the work is followed by a detailed account of the cutting of a main-rod big-end for a steam locomotive.

Studies of the Oxy-Acetylene Cutting Process. H. R. Bullock. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 50–52). After referring to the difficulties of applying certain refinements to the standard technique of oxygen cutting, the author points out the effect of periodic gas-stream fluctuations on the smoothness of the cut and the difficulty of exhibiting these by Schlieren's method. An account of the use of the shadow method with a very high-speed camera is then presented as being the best method of investigation.

The Oxygen-Cutting of Cast Iron and Rustless Steels with the Aid of a Rod. (Soudeur-Coupeur, 1937, vol. 16, Oct., pp. 1–7). In the oxygen-cutting of cast iron, three difficulties arise: (1) The graphite present prevents the iron from "burning"; (2) the temperature at which iron begins to burn is above the melting point of cast iron; and (3) the oxide formed melts at a higher temperature than the cast iron. One way of overcoming these difficulties is to use more acetylene in the heating flame, but an alternative means of generating the extra heat necessary is described in this article. Briefly, the work piece is heated by the cutting blowpipe as usual, and then a rod of iron or steel is fed into the oxygen jet; the burning of the rod liberates the additional heat required, and so enables the cutting process to proceed. When rustless steels are oxygen-cut, they likewise become covered by a protective coating of nickel and chromium oxides, and here again the use of the steel rod gets over the difficulty. Some operating details and examples of the cutting of cast iron and rustless steels are given.

PROPERTIES AND TESTS

(Continued from pp. 31 A–38 A)

Elimination of the Influence of Thickness in Cupping Tests on Thin Sheet Metal. (Sheet Metal Industries, 1937, vol. 11, Oct., pp. 898–903). An English translation of an article by Marchand, the original of which appeared in Revue de Métallurgie, Mémoires, 1937, vol. 34, Aug., pp. 472–474. (*See* p. 32 A).

Evaluation of the Maximum Error Arising from the Application of the Principle of De Saint Venant to an Isotropic Solid. O. Zanaboni. (Atti della Reale Accademia Nazionale dei Lincei, Rendeconti Scienze Fisiche, Matematiche e Naturali, 1937, vol. 25, June 4, pp. 595–601). The author discusses the determination of the error resulting from the assumptions made in the principle of de Saint Venant for combining stresses. The determination refers to stresses in isotropic bodies.

The Behaviour of Cast Iron Under Alternating Tension-Compression Stressing. A. Pomp and M. Hempel. (Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1125–1127). The fatigue strengths of two cast irons of the following analyses were investigated : (*a*) Total carbon 3·04%, graphite 2·30%, combined carbon 0·74%, silicon 1·92%, manganese 0·64%, phosphorus 0·53%, sulphur 0·076%; (*b*) total carbon 3·09%, graphite 2·31%, combined carbon 0·78%, silicon 2·07%, manganese 0·69%, phosphorus 0·15%, sulphur 0·15%. The corresponding mechanical properties were: (*a*) Brinell hardness (10/3000/30) 197, tensile strength 17 kg. per sq. mm., compressive strength 71 kg. per sq. mm., and (*b*) Brinell hardness 202, tensile strength 24 kg. per sq. mm., compressive strength 91 kg. per sq. mm. Alternating tensile and compressive stresses of different mean values were applied in a 60-ton machine at the rate of 500 alternations per minute. From the data obtained, endurance strength diagrams were derived. The ratio of intrinsic fatigue resistance to tensile or compressive stress, and the ratio of tension-compression endurance strength to tensile strength are discussed.

Limiting-Stress-Range Diagrams of Round and Flat Steel Bars, T Girders and Steel Wires. M. Hempel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Nov., pp. 231–240). Alternating tension-compression stress tests of various carbon and nickel-chromium steels above and below the elastic limit indicate that an increase in the elastic limit is connected with an increase in the range of limiting stress, and that after the original elastic limit is exceeded, an almost sudden change occurs in the limiting-stress-range diagram. The results of repeated tensile stressing of round and flat bars show that the strength of the latter is lower than that of the former under these conditions; the ratio of the fatigue strength of solid bars to that of drilled bars was as 1·32 : 1·73, and the fatigue strength of

bars with all-machined surfaces was about 1–3 kg. per sq. mm. higher than that of bars from which the rolling skin was not removed. The influence of section form and size on the results proved to be insignificant. The boundary lines in the limiting-stress-range diagrams for undeformed plain carbon steel bars and bars elongated by about 10% pursued a parallel course, the mean value for the deformed bar being about twice that of the undeformed bar. In a further series of tests diagrams were constructed for welded and bolted T girders and for bolts stressed by alternating bending and in tension respectively. Diagrams were also constructed to show the behaviour of various steel wires under periodic tensile stress in air and when sprayed with water; no effects due to drawing conditions, particularly the reduction and the lubricant employed, could be determined. In conclusion, the influence of the velocity of the application of the stress, the type of stress, the structure and the carbon content on the fatigue strength was briefly noted.

The Fatigue Resistance of Steel as Affected by Some Cleaning Methods. J. H. Frye, jun., and G. L. Kehl. (American Society for Metals, Oct., 1937, Preprint No. 16). An investigation was made to determine the effect of some descaling methods on the endurance limit of steel. Particular attention was paid to scale removal by sand, steel shot and steel grit blasting. A correlation was made between the surface condition and the fatigue limits. The relation between the angle of blasting with sand dust and the blasting pressure is shown. Complete fatigue curves are presented together with corresponding photomicrographs of the blasting medium used and the resulting notch development.

The Effects of Longitudinal Scratches on Valve Spring Wire. F. P. Zimmerli, W. P. Wood and G. D. Wilson. (American Society for Metals, Oct., 1937, Preprint No. 24). The authors describe the results of a study carried out to develop a method of measuring the depths and contours of surface scratches on spring wire, and to determine the effects of scratches with varying depths and contours upon the endurance limit in torsion of a typical steel spring wire. A special type of machine for carrying out torsional fatigue tests upon small sections of wire was designed and built. Scratches of controlled depth and contour were produced upon straight-wire sections and their endurance limit in torsion was compared with that of the same wire in the unscratched condition. The presence of longitudinal scratches lowers the endurance limit of the wire to an appreciable extent. The decrease in endurance limit produced by the scratches was not, however, as great as the differences observed between polished and commercial wire when in the form of helical springs. The contours of the scratches were much more important than the depths of the scratches. Mechanical defects such as scratches produced during drawing and coiling operations can never be as serious in causing spring failures as seams produced in the wire during the manufacture of the wire.

Fatigue Properties of Helical Springs. R. R. Tatnall. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 577–591). The author discusses factors affecting the fatigue properties of springs and refers to the results of previous investigations and to research undertaken by himself. The factors considered include hardness and grain size in addition to surface conditions of various types. Graphical data are presented.

A Continuous Hardness Test : Periodic Hardness Fluctuations. E. G. Herbert. (British Association : Engineering, 1937, vol. 144, Oct. 29, pp. 495–496). A new type of continuous hardness-testing machine is described. (*See* p. 33 A).

British Standard Method and Tables for Brinell Hardness Testing. (British Standards Institution, No. 240–1937).

Precipitation Hardening of Cobalt Steel : A New Tool Material. R. H. Harrington. (American Society for Metals, Oct., 1937, Preprint No. 4). The author describes the properties and characteristics of an alloy steel containing 36% of cobalt, 8% of molybdenum, 6% of chromium, 1% of carbon, and 0·4% of vanadium. The alloy can be forged, cut, machined, welded and brazed, and can be precipitation-hardened to a hardness of Rockwell A 88 or Rockwell C 72. Tests indicate that as a tool material the alloy may be classified as intermediate between high-speed steel and sintered carbide materials.

Flux Distortion in Iron Testing. J. Greig and J. E. Parton. (British Association : Engineering, 1937, vol. 144, Oct. 15, pp. 439–441). The authors discuss the utility of distortion-factor measurements as measures of flux distortion. The filter-bridge and potentiometric methods of determining the distortion factor are considered and the results obtained by means of each are compared. Data are presented in graphical form.

On the Thermochemistry of Alloys. II. Direct Determination of the Heats of Formation of Ternary Alloys : Iron-Nickel-Aluminium, Iron-Cobalt-Aluminium, Copper-Nickel-Aluminium, Iron-Aluminium-Silicon, together with a Series of Alloys of the Copper-Manganese-Aluminium System. F. Körber, W. Oelsen, and H. Lichtenburg. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 11, pp. 131–159). An extension and continuation of previous work (*see* Journ. I. and S.I., 1937, No. I., p. 147 A). The molten metals from which the alloys were made were allowed to react in a specially adapted crucible arranged to constitute a water calorimeter and the total heat produced was measured. The mixing technique and sources of errors in the values deduced for heats of combination are discussed. Results are presented in tabular and in graphical form, and certain diagrams for the systems examined are presented, showing the heat-of-formation surfaces. The relationships between the heats of formation and the composition were very similar in both binary and ternary systems. The transformation processes in the low-alu-

minium solid solutions occurring in the iron-nickel-aluminium and the iron-cobalt-aluminium systems, especially at the α boundary, exercised a marked effect on the heat-of-formation surfaces.

On the Thermochemistry of Alloys. III. The Heats of Formation of the Binary Alloys Iron-Antimony, Cobalt-Antimony, Nickel-Antimony, Cobalt-Tin, Nickel-Tin, Copper-Tin, and Copper-Zinc, Prepared by the Mixing of the Molten Metals. F. Körber and W. Oelsen. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 15, pp. 209–219). (*See* previous abstract). The heats of formation of a series of binary alloys were determined directly in a water-calorimeter specially designed for the purpose. Among other alloys examined were those of iron and antimony, for which the heats of formation were determined over the whole range of concentrations. The results obtained are discussed in relation to the equilibrium diagrams. The heat of formation of the iron-tin alloys could not be determined by the direct method owing to dissociation of the intermetallic compounds taking place in the molten state. The tin and antimony alloys of iron, cobalt and nickel gave heats of formation of increasing magnitude from iron to nickel.

Mechanical Properties of Some Special Steels at Low and High Temperatures. E. S. Tovpenez. (Katshestvennaia Stal, 1937, No. 3, pp. 47–48). The author has investigated the mechanical properties, in the temperature range of — 60° to 600°, of the following four steels: (*A*) 2·44% chromium, 1·38% nickel, 0·35% molybdenum; (*B*) 0·32% chromium, 3·32% nickel, 0·38% molybdenum; (*C*) 0·96% chromium, 0·43% molybdenum, 0·17% vanadium; and (*D*) 1·12% chromium, 0·44% nickel, 0·34% molybdenum. The change in properties with temperature is smoother in special steels than in carbon steels, and the decrease in notch toughness at low temperatures (as well as at 450°) is slighter. The limit of proportionality and the temporary resistance are larger than in carbon steel and remain rather high even at 600°. Between — 40° and + 150° the mechanical properties of the special steels investigated were practically constant, especially of steels *A* and *B*. (In Russian).

The Accuracy of the Martens Mirror-Extensometer in Creep Testing. L. Wizenez. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 189–193). Formulæ employed in creep tests in which extensions are measured with the Martens mirror-extensometer are examined and the conditions under which such formulæ are applicable are discussed. The source and removal of systematic errors are also discussed.

A New Application for the Short-Time High-Temperature Tensile Test. C. L. Clark, A. E. White and G. J. Guarnier. (American Society for Metals, Oct., 1937, Preprint No. 11). The authors present the results of short-time high-temperature tensile tests on carbon steel, chromium-molybdenum-silicon steel, and

molybdenum steel over a range of temperatures. The rate of load application, and thus the rate of deformation as well as the time for fracture, were varied and the resulting tensile strength values were correlated with the speed of testing. On this basis an apparently critical temperature was found to exist which differed for each of the analyses considered. Furthermore, the magnitude of this temperature appears to give an indication of the creep characteristics at temperatures in its vicinity. This method may serve therefore as a type of an acceptance test in indicating whether or not steels of the same general type and composition possess the same creep strength.

Influence of Heat Treatment on Creep of Carbon-Molybdenum and Chromium-Molybdenum-Silicon Steel. R. F. Miller, R. F. Campbell, R. H. Aborn and E. C. Wright. (American Society for Metals, Oct., 1937, Preprint No. 17). The authors discuss the creep behaviour of a variety of structures produced in two steels by different heat treatments prior to creep testing. The apparatus and technique employed are briefly described. The authors used the least-square method of analysis for the interpretation of the creep data, which eliminates the personal error involved in graphical analysis, and permits the expression of creep rates which are not constant with time. Specimens of a carbon-molybdenum steel were tested for 3000 hr. at 1100° F. after normalising and after six different tempering treatments. The most creep-resistant structure contained a fine shower precipitate. Specimens showing the greatest change of structure during the creep test also had the greatest tendency to develop an increasing creep rate, and structural stability accompanied a constant creep rate. Mechanical tests indicated that time at temperature under stress lowers the strength and slightly increases the ductility. Creep tests were also carried out on a normalised and tempered chromium-molybdenum-silicon steel at 850°, 950° and 1100° F. Little change of structure occurred during the tests except at 1100° F., where some coarsening of the carbides was noted. At 1100° F. the annealed material possessed greater creep resistance than that which had been normalised and tempered.

The Rupture Strength of Steels at Elevated Temperatures. A. E. White, C. L. Clark and R. L. Wilson. (American Society for Metals, Oct., 1937, Preprint No. 9). The authors present the results of long-time rupture tests on carbon steel, chromium-nickel steel, chromium-molybdenum steel, chromium-silicon-molybdenum steel, and chromium-molybdenum-titanium steel, carried out at temperatures from 1000° to 1500° F. The time for fracture was varied from a few minutes to several thousand hours. A definite relationship was found to exist for each analysis between stress and fracture time. The chief merits of the rupture tests were found to be that (1) they serve as a suitable basis for the design of high-temperature apparatus in which some deformation of the parts is permissible,

and (2) they afford the best means available for determining the ductile properties of steels under the combined action of stress, time and heating.

Steel for High Vapour Pressures and High Temperatures. G. T. Liberman. (Katshestvennaia Stal, 1937, No. 3, pp. 29–35). The author has investigated the properties of five steels (1) 1·09% manganese, 0·39% silicon, 0·58% molybdenum; (2) 1·10% manganese, 0·36% silicon, 0·52% molybdenum, 0·72% chromium; (3) 1·11% manganese, 0·30% silicon, 0·24% molybdenum, 1·05% copper; (4) 0·37% manganese, 0·87% silicon, 0·61% molybdenum, 1·11% copper; and (5) 0·52% manganese, 0·30% silicon, 0·60% molybdenum, 0·35% aluminium. The critical points were determined dilatometrically. The influence of thermal treatment on the mechanical properties was investigated; the best results were obtained by normalising and tempering. The main subjects of the paper are the mechanical properties of the five steels investigated at temperatures up to 700° C.; their ageing; and oxidation by air and water vapour. The highest heat resistance was shown by the chromium-manganese-molybdenum steel No. 2. This steel was superior to the chromium-nickel-molybdenum and chromium-silicon-molybdenum steels now in use as heat-resisting materials. Satisfactory results were also obtained with the manganese-molybdenum steel No. 1. The addition of copper to steels Nos. 3 and 4 was not especially favourable with regard to ageing. The addition of aluminium, as in steel No. 5, prevented ageing but impaired the mechanical strength of the metal. It is therefore advisable to use aluminium in quantities smaller than those used in the preparation of steel No. 5, *e.g.*, 0·1–0·15%. (In Russian).

Tensile Fatigue Strength at High Temperature. (Metal Treatment, 1937, vol. 3, Summer issue, pp. 89–94). A translation into English of an article by M. Hempel and H. E. Tillmans which appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1936, vol. 18, No. 12, pp. 163–182. (*See* Journ. I. and S.I., 1937, No. I., p. 80 A).

The Behaviour of Heating-Element Alloys in Different Gases at High Temperatures. W. Hessenbruch, E. Horst and K. Schichtel. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Nov., pp. 225–229). In order to select the most satisfactory material for the heating elements of an electric resistance furnace, more especially for use under special conditions, the life of heated spirals subjected to the action of slow streams of various commercial gases was determined. Nickel-chromium, nickel-chromium-iron, and chromium-aluminium-iron alloys were tested, the first two at 1050° C., and the last at 1200° C. It was shown that only pure hydrogen exerted no effect on the materials constituting the heating element. Gases containing carbon, particularly under reducing conditions, as, for example, water gas, provoked carburisation, which was the more intense the greater the iron content and the lower the aluminium

content of the material being tested. Nitrogen reacted with the nickel-chromium-iron alloys and with the chromium-aluminium-iron alloys to form nitrides; in the case of the latter group of alloys pronounced impoverishment in chromium and aluminium resulted from this reaction, and the life of the element was appreciably decreased. Nickel-containing alloys were shown to be very sensitive to attack by sulphur and sulphur compounds, and evidence was obtained of effects due to moisture in the furnace gases. In general it was demonstrated that austenitic alloys are especially sensitive to intercrystalline corrosion, whilst ferritic alloys are subjected to a practically uniform oxidising action over the entire surface of the specimen.

Non-Metallic Elements in Steel. Hydrogen, Sulphur and Nitrogen. T. G. Bamford. (Staffordshire Iron and Steel Institute: Foundry Trade Journal, 1937, vol. 57, Oct. 21, pp. 323, 326; Iron and Coal Trades Review, 1937, vol. 135, Oct. 8, p. 577). After discussing the mechanism of diffusion of hydrogen into steel, the author considers the effects of the gas on steels and, in particular, on nickel-chromium steels; means of avoiding hydrogen absorption are mentioned. Sulphur and sulphur removal are also dealt with, with particular reference to the desulphurising action of calcium and magnesium. The anomalous behaviour of nitrogen is referred to at length.

Cast Irons for Commercial Motor Vehicles. W. P. Eddy. (International Foundry Congress, Paris, 1937: Foundry Trade Journal, 1937, vol. 57, Sept. 23, pp. 250–252). The author describes briefly the chemical and structural characteristics of the irons used for components such as cylinder blocks and liners, cylinder heads and valve seats, exhaust manifolds, and brake drums and clutch plates in commercial road vehicles. Tabular data on typical compositions are given.

Cast Iron for High Acid Resistance. W. E. Schreck. (Giesserei, 1937, vol. 24, Nov. 5, pp. 561–564). The author discusses briefly the uses and requirements of acid-resisting cast iron in the chemical industry, enumerates the compositions of irons designed to withstand different acids, and then discusses, with tabular data, the solubility of irons of various compositions in sulphuric acid (50° Bé. at 100° C.), with special reference to the carbon content and to the influence of graphite. The influence of design on the acid resistance of chemical equipment is also noted, and in conclusion the author discusses the high-silicon acid-resisting irons.

Concerning Cast Alloys of the Silal Type Resistant to Heat and to Scaling. E. Piwowarsky. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 257–260). Cast iron alloys resistant to heat and to scaling (such as have been developed in Germany, England, France and Belgium) are discussed. The high-nickel austenitic cast alloys rich in silicon are much superior in toughness to the ferritic cast alloys of the Silal type, but the addition of nickel to the latter type appears to have no favourable effect. By careful control of the alloying

additions, particularly of the silicon, aluminium and chromium alloys remarkably resistant to growth and scaling may be prepared but the toughness and machinability of such alloys have still to be improved.

On the Transverse Strength of Malleable Cast Iron and Cast Steel. F. Roll. (Giesserei, 1937, vol. 24, Nov. 5, pp. 557–560). From a series of experiments, the data for which are presented in graphical and tabular form, the author concludes that the transverse strength of whiteheart malleable iron is between 70 and 120 kg. per sq. mm. The figure obtained, however, is conditioned by the shape of the test-piece; a round bar gives higher values than a square bar, but the former gives more variable values. With an increasing ratio of the distance between the supports to the diameter, the transverse strength drops slightly. Blackheart malleable iron gives transverse strengths between 65 and 95 kg. per sq. mm.; round and square bars give practically the same value, and the strength drops with an increasing ratio of the distance between the supports to the diameter of the test-piece. The transverse strength of a 12-mm. rod is 40–140% higher than the tensile strength in the case of a whiteheart malleable iron, and 65–140% higher than the tensile strength in the case of a blackheart malleable iron. The latter iron, however, has a higher and more uniform transverse strength than whiteheart iron, although it exhibits greater surface sensitivity. Cast steel gives a transverse strength two to three times as great as its tensile strength.

The Effect of Mass upon the Mechanical Properties of Cast Steel. C. W. Briggs and R. A. Gezelius. (American Society for Metals, Oct., 1937, Preprint No. 15). Medium-carbon cast steel and medium-manganese cast steel were studied to show the effect of mass upon the mechanical properties. Coupons varying from ½ to 8 in. in cross-section were cast, and tensile test-bars were prepared and tested in both the as-cast and the annealed condition. Density measurements and photomicrographs were obtained, and segregation studies were made on the various sections. A comparison was made between the results obtained from the coupons and the test-bars of various diameter cast to size. The effect of pouring temperature on the mechanical properties, and the effect produced by high-temperature heat treatments were also studied.

Influence of Deoxidation by Aluminium on the Sensitivity of Carbon Steel to Overheating and on its Mechanical Properties. K. A. Malyshev and S. S. Steinberg. (Katshestvennaia Stal, 1937, No. 2, pp. 11–17). The authors compare three ingots of soft steel (0·35% carbon). To one no aluminium was added before casting; one was deoxidised with 0·03% of aluminium and one with 0·05% of aluminium. Samples of the three steels were heated to different temperatures (800–1250°) and either slowly cooled or quenched, then heated for a second time to 860° and again either quenched or slowly cooled. The microstructures and mechanical properties were

investigated after each stage in the thermal treatment. The addition of aluminium retards the growth of the austenite grain below 1000°, but accelerates it above 1000°. In the interval 950–1050° steel deoxidised with aluminium shows a very heterogeneous grain. The second heating (to 860°) has no effect on the grain size of non-deoxidised steel, but breaks up the grain of the deoxidised steel (in the samples in which large grains were grown by heating above 1000°). In the small-grained aluminium-treated steel (*i.e.*, steel heated below 1000°) a second heating causes a partial growth of the grains, giving a mixed structure. In slowly-cooled samples deoxidised steel shows a tendency to assume a globular structure, whereas the non-deoxidised steel gives a network structure. The pearlite assumes the form of grains in the first case and a lamellar form in the second one. The impact resistance of the longitudinal samples of aluminium steel—even of those with larger grains—is higher than that of the non-deoxidised steel. High-temperature annealing (1150–1250°) followed by an ordinary annealing improves the toughness of deoxidised steel. On the whole, the influence of aluminium is remarkably strong. A decision between the two theories of this influence (submicroscopic inclusions of alumina or solution of aluminium in the austenite) cannot yet be arrived at. (In Russian).

Chromium-Tungsten-Vanadium Steel for High-Efficiency Hot-Die Blocks. V. A. Erachtin. (Katshestvennaia Stal, 1937, No. 2, pp. 40–44). The author has investigated the steel *3Ch.V.*8 (0·22–0·35% carbon, 2·20–2·70% chromium, 7·5–9% tungsten, 0·2–0·5% vanadium). For rolling or forging it must be heated to a sufficiently high temperature to finish the treatment at 850°. The tools must be cooled in hot ashes or isothermally, *i.e.*, by keeping at 700–730° for 2–3 hr. and then cooling. After softening at 750°, the steel has a Brinell hardness of 255–207. The tools are best quenched from 1050–1100° (in no case higher than 1150°), and tempered at 550°. The properties of the steel depend strongly on its carbon content; the author recommends that it should be increased from 0·22–0·35% to 0·28–0·38%. (In Russian).

The Structural Steels. L. Persoz. (Métaux, 1936, vol. 11, Oct., pp. 190–194). The continuation of a series of articles on the properties of structural steels (*see* Journ. I. and S.I., 1936, No. II., p. 265 A). The author discusses the influence of alloying elements and impurities on the properties of the steels.

Substitute for High-Speed Steel. (Katshestvennaia Stal, 1937, No. 3, p. 48). The following steel is recommended by the Central Institute of Metals as a substitute for high-speed steel; it is produced by the Electrostal Works: 1·0–1·15% carbon, 1·1–1·7% silicon, 11·0–13·0% chromium; 2·1–2·5% vanadium. It should be quenched from 1240–1260° in oil and tempered for 4 hr. at 550°. (In Russian).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 39 A–41 A)

A Note on Rapid Photomicrography. W. Mutchler and H. O. Willier. (American Society for Metals, Oct., 1937, Preprint No. 6). A rapid and relatively inexpensive method for making photomicrographs on a metallographic microscope is described. An apparatus, designed to hold roll film or paper, is substituted for the individually loaded film-holders used in ordinary practice. The use of an auxiliary focusing eyepiece makes it unnecessary to remove the holder when focusing, since the image is duplicated upon the independent eyepiece. Bromide emulsion photographic papers, of appropriate thinness, may be used for repetition work. The image obtained on the paper negative shows sufficient detail for many purposes, and may eliminate the need for prints. Prints of good quality can be made, however, from the paper negatives.

Contribution on the Sources of Error in the Preparation of Micro-Sections. F. Roll. (Metallwirtschaft, 1937, vol. 16, Nov. 12, pp. 1179–1184). The author examines the possible sources of error in preparing microsections of metals. The grinding operation may result in overheating, which will produce, if it is severe enough, temperatures up to 950° C. for a depth of 1 mm. Polishing may result in flowing of the surface of the metal and the tearing out of constituents; polishing compound may be ground into the surface. In addition, the polishing operation promotes the chemical reactivity of the metal surface; gases such as nitrogen and oxygen may react with the metal, and in non-ferrous and ferrous metals and alloys both oxides and nitrides may be observed. Further errors may arise consequent upon the choice of an unsuitable etching reagent or upon the use of too-prolonged an etching period, which may modify the structure. Errors in the preparation of cast iron, malleable iron and steel microsections are cited in the text.

Direct Observation of Structural Alterations at High Temperatures by Means of the Electron Microscope. W. G. Burgers. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 250–251). The technique of investigating structural alterations in heated metals by means of the electron microscope is described. The results obtained by this technique are briefly compared with those deduced by the etching technique. The electron-microscopic method is particularly suited to the study of transformations and recrystallisation processes, and the $\alpha \rightleftharpoons \gamma$ transformation in iron is referred to in the paper.

X-Ray Methods of Studying Stress Relief in Welds. J. T. Norton. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 19–22). The author describes the apparatus and technique

for determining elastic strains in welded specimens employing the X-ray diffraction camera. In the experimental work described cobalt $K\alpha$ radiation from a tube operating at 10 m.amp. and 40 kV. was used. The mechanism of plastic and elastic strains is discussed briefly and the means of determining data by X-ray diffraction and interpreting them are treated at some length.

An Alternating-Current Non-Destructive Test for Welded Seams. W. B. Kouwenhoven and A. E. Vivell. (Welding Journal, 1937, vol. 16, Oct., Supplement, pp. 47–50). In the method of non-destructive testing of welds developed by the authors, the welded seam to be examined is magnetised by a strong alternating magneto-motive force. Two search coils are connected in opposition and are placed on the seam so that any stray field present cuts their windings; the wave-form of the electromotive force induced is examined by means of an oscillograph and the presence or absence of flaws in the weld is deduced from the characteristics observed. Typical wave-forms arising from lack of uniformity in the weld are illustrated and discussed.

Fundamental Knowledge Concerning Martensite. E. Hugony. (Metallurgia Italiana, 1937, vol. 29, Oct., pp. 521–535). The author reviews structural phenomena observed during the quenching of steel, and discusses the properties of martensite and various hypotheses concerning its nature. The tetragonal and cubic forms are discussed at length, together with the lattice-distortion theory purporting to explain the hardness of this constituent.

Electromagnetic Measurements and Steel Structures Correlated. C. Kinsley. (American Society for Metals, Oct., 1937. Preprint No. 8). The author describes electromagnetic measurements of the structural changes in steel due to decarburisation and heat treatment, and the procedure for their identification by the balancing wave method of measurement. The preparation of the testing circuit for the reception of the sample to be tested is of critical importance. Before a sample has been treated so as to change its structure, it is placed in the magnetising coil and the electromotive force induced in the testing circuit is measured with respect to an empty coil—an air core. This initial electromotive force is completely balanced by introducing into the circuit an equal, but opposing, electromotive force. This is synthesised from the electromotive force derived from any convenient piece of steel supplemented by phase-shifting transformers which term-by-term neutralise the induced electromotive force. The opposing electromotive force is called the " balancing wave," and it has an opposite sign with respect to the corresponding induced electromotive force. Each sample is now treated so as to change its structure. It is then placed in the magnetising coil and the value of the additional electromotive force resulting from the treatment is obtained as a series of harmonic terms. The amplitude and phase angle of each of the significant terms of the complete wave are evaluated and their

interpretation gives the character and the amount of the change produced in the steel sample. Illustrations are given of the metallurgical differences between the samples and between the different sections of the same sample, also of the effect of different tempering temperatures on similar samples which had been quenched alike. The significance of different phase angles with similar electromotive-force waves is illustrated by superimposed curves. The relation of the phase angle to the character of the change in the steel structure is pointed out.

A Study of Deoxidation Type Inclusions in Alloy Steels. W. A. Hare and G. Soler. (American Society for Metals, Oct., 1937, Preprint No. 27). The authors summarise the results of a series of tests on deoxidation-type inclusions as they occur in alloy steels and discuss the formation and effect of various types of inclusions as they occur in commercial steels. Inclusions were separated from the steel by chemical means. After separation, metallographic, petrographic, X-ray studies and chemical analyses were made, to determine the mineralogical phases of various types of non-metallic inclusions in several types of steel. The relation existing between the known inclusion phases and equilibrium diagrams of the oxides is discussed. The effect of variations in furnace practice on inclusions is discussed in some detail and a table is presented showing the chemical analyses of the inclusions, their mineralogical phases, the deoxidation practice used in making the steel and the percentage of FeO in the steel before the final deoxidation was effected as determined by analysis of the gases evolved from the molten metal.

The Initial Stages of Graphitisation. H. A. Schwartz and M. K. Barnett. (American Society for Metals, Oct., 1937, Preprint No. 18). The authors have carried out a re-investigation of the course of the time-graphite curves for cast iron with special reference to the interval when but little graphite has formed. It is shown that the previously established relation in which the amount of graphite is proportional to the $\frac{3}{2}$ power of the time may be preceded by an interval in which graphite quantity increases very slowly, in direct proportion to time. This interval is probably that considered by other investigators to be an incubation period before the start of any reaction.

Graphitisation in High-Purity Iron-Carbon Alloys. C. Wells. (American Society for Metals, Oct., 1937, Preprint No. 20). The behaviour of high-purity alloys, of carbon contents between 0·13 and 2·98%, caused by the presence of graphite, was studied by dilatometric and microscopical methods. Cementite is shown to be unstable at temperatures below the eutectic temperature. The effect of the rate of heating and cooling (2° C. to $\frac{1}{8}$° C. per min.) on the superheating and undercooling in iron-carbon alloys containing graphite was also studied. An iron-graphite equilibrium diagram for the vicinity of the eutectoid is given; its accuracy is about $\pm$ 5° C. It is shown that the rate of graphitisation of the above alloys is greatly increased by the presence of graphite nuclei, and the rate of decomposition of

carbide in graphite + austenite is considerably increased as the temperature is increased. Evidence is given to show that in hypereutectoid alloys two austenites of similar mass and containing in solution the same concentration of carbon may have at the same temperature two different volumes, depending upon whether the carbon came from graphite or carbide. The mechanism of graphitisation is discussed, and it is shown that graphite may form directly from austenite as well as from carbide. Graphite was found in the crystallographic planes in carbide masses. Evidence is presented which indicates that the carbide may change in composition during graphitisation. Different structures arising from different conditions of graphitisation were observed, and a discussion of them is given.

The Formation of Graphite and Cementite in Hypereutectic Iron-Carbon Alloys. H. Gröber and H. Hanemann. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 199–202). The authors' experiments on the X-ray interference phenomena yielded by graphite separated from hypereutectic and eutectic alloys of iron and carbon indicate that the decreased sharpness of the fringes yielded by the eutectic alloys is caused by the presence of greater quantities of secondary graphite, which possesses a sub-microscopic crystalline structure. White hyper-cementitic alloys exhibit a constituent which may be considered as spherolitic primary graphite; its presence is to be attributed to solidification beginning in the stable and continuing in the metastable system.

Concerning the Structure of Binary Alloys. R. Becker. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 245–249). The author presents a quantitative expression for the mechanism of phase precipitation in binary alloys, based on thermodynamic considerations.

Abnormal Grain Growth and the Annealing of Low Carbon Steel Wire. B. L. McCarthy. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 535–544). After a brief discussion on the phenomena of grain growth and recrystallisation in steel, the author examines the first phenomenon in the case of steel wire. Experimental work is described on four low-carbon steels—two rimming and two killed—the normal grain size of these materials being compared with that induced by annealing after straining. Abnormal growth is shown to occur without straining in the rim of rimmed steels; a parallel observation is made in the case of electrolytic iron, but the phenomena are differentiated. The influence of segregation and of the lag in the transfer of strain from the outer to the inner sections of heavy masses is also demonstrated.

Relation of Pre-Treatment of Steels to Austenitic Grain Growth. J. E. Dorn and O. E. Harder. (American Society for Metals, Oct., 1937, Preprint No. 14). The authors suggest that aluminium-killed steels contain a grain-growth inhibitor, the solubility of which in ferrite and in austenite increases with an increase in temperature, and at the upper end of the ferrite temperature range is

greater than at the lower end of the austenite range. On the basis of this hypothesis a possible mechanism is suggested for the relation of the pre-treatment of steels to the austenitic grain growth. This hypothesis was tested first by heating steels at temperatures below the critical range, in one case to just below the critical range to produce the maximum solubility of the grain-growth inhibiting material in ferrite and in the other case, first, at a relatively high temperature and then for longer periods of time at lower temperatures to effect a lower solubility of the inhibitor in the ferrite. In general, the steels which were saturated with the grain-growth inhibitor at temperatures just below the critical range showed a higher coarsening temperature or less coarsening at a given temperature than those which were heat-treated to give a lower amount of inhibitor in solution. Specimens which were heated directly from the saturation temperature or quenched and then rapidly reheated were more inclined to be fine-grained than those which were slowly cooled from the saturation temperature and then reheated. Specimens which were given a higher-temperature treatment in the austenite range to effect solution of the inhibitor and quenched had a pronounced tendency to be fine-grained, whereas specimens with a similar treatment but slowly cooled tended to be coarse-grained. In a qualitative way the experimental results supported the mechanism postulated.

Austenitic Grain Size of Eutectoid Steel. H. Tobin and R. L. Kenyon. (American Society for Metals, Oct., 1937, Preprint No. 7). The authors describe a special technique by which the size of the austenitic grains in eutectoid steels can be very clearly shown, and also give a modification which makes it possible to determine the size of the initial austenitic grains in a piece of material which has already been heat-treated. This method of examination has been applied to a study of the effect of previous austenitic grain size and rate of heating through the critical temperature on the resultant austenitic grain size. An investigation has also been made with this technique to show the characteristic austenitic grain-growth behaviour of a eutectoid steel. It is brought out in the paper that only by such a study can the behaviour of a steel be determined for the entire range of heat treatments to which it may be subjected.

Some Factors Influencing Austenitic Grain Size in High Purity Steels. G. Derge, A. R. Kommel and R. F. Mehl. (American Society for Metals, Oct., 1937, Preprint No. 13). To determine the relative importance of aluminium in solid solution and finely dispersed alumina in controlling the austenitic grain size of steels, high-purity iron-aluminium samples were prepared by diffusing aluminium into hydrogen-purified carbonyl iron. To obtain iron-alumina samples the iron-aluminium material was treated in hydrogen containing a small amount of oxygen. Additional samples were made by the vacuum fusion of aluminium with purified and unpurified carbonyl iron. The same diffusion technique was used in preparing samples with silicon and silica. An oxygen-free

hydrogen-hydrocarbon gas was used to carburise the irons, and the grain-growth characteristics of the resultant steels were determined. The experiments showed that grain growth is inhibited by the refractory oxides, and that the magnitude of the effect is sensitive to the dispersion of the oxide. Pack carburisation of the same samples produced abnormal structures in all the materials, indicating that abnormality is due to oxygen in the carburising gas rather than to oxides in the metal.

Determination of the Grain Size of Steels by the Oxidation Method. P. T. Grusdov and I. M. Fedorchenko. (Katshestvennaia Stal, 1937, No. 3, pp. 40–46). The authors first discuss the usual method of determining the grain size by carburisation, and stress its limitations. This treatment reveals the grain size as produced by a thermal treatment different from that used in practice, and it is further affected by the presence of the excess carbon. The authors then proceed to describe a new method, which consists in the oxidation of a polished steel surface by atmospheric oxygen in a furnace at a temperature above Ac_3. After removing the surface oxide layer by polishing, the samples are etched for 0·5–10 min. in 4% picric acid solution. The boundaries of the grains appear as dark lines, on account of the diffusion of oxygen into the metal mainly between the grains, so oxidising the carbon on the surface of the grains and forming dark layers of ferrite. Sections prepared perpendicular to the surface show that the oxygen penetrates to a depth equal to one or two grains. The authors investigated in this way eleven types of carbon and special steels. For three steels the results were compared with those obtained by normalising; the same grain size was obtained by both methods. (In Russian).

Grain-Size Control of the Steels Ch.12 and Ch.12M. N. N. Lipchin. (Katshestvennaia Stal, 1937, No. 2, p. 54). The grain size in these steels—which are of the ledeburitic type—can be determined by heating to 1150° for 15 min., quenching in oil and tempering at 540–560° for 45–60 min., thus producing a troostite network round the austenite grains. (In Russian).

Application of the Hahn Emanation Method to Problems in Metallography. W. Seith and G. Küpferle. (Zeitschrift für Metallkunde, 1937, vol. 29, July, pp. 218–222). The suitability of Hahn's emanation method for indicating the course of the following processes was demonstrated: Recrystallisation; order and disorder changes in lattices; lattice transformations; reactions involving atomic-interchange (*Platzwechsel*) on the heating of metal powders; reactions between metal powders; and the diffusion of emanation in lead. The method proved appropriate for following all processes in metals involving ordering of the lattice and hence a diminution in the mobility of the atoms composing the lattice. It was also suitable for following the sintering process in metal powders, which is associated with a decrease in the effective surface of the powder. Thorium X was employed as the activating agent.

An X-Ray Study of the Ar_3 and Ac_3 Points of Iron and Iron-

Nickel Alloys. S. D. Smith. (American Society for Metals, Oct., 1937, Preprint No. 19). Samples of iron and iron-nickel alloys of a high degree of purity and homogeneity were prepared by the precipitation of the hydroxides, which were subsequently reduced in pure hydrogen and worked to form wires or ribbons as desired. These wire or ribbon samples were heated under carefully controlled conditions of temperature in an atmosphere of pure hydrogen, and photographs were made of the X-ray diffraction patterns using Coolidge X-ray tubes with molybdenum targets. Practically monochromatic radiation was obtained by using zirconium oxide filters. The value of a reversible A_3 point for iron of high purity and values for the Ar_3 and Ac_3 points of iron-nickel alloys containing up to 5·3% of nickel were determined.

The Rate of Austenite Transformation in Cast Iron. D. W. Murphy, W. P. Wood and D. Girardi. (American Society for Metals, Oct., 1937, Preprint No. 23). The authors report a further study on the resolution of the austenitic grain size in cast iron. The macro-grain-size pattern appears to be a trace of a condition arising soon after solidification is complete. A fine network structure representative of the austenitic grain size on reheating and outlined by nodular troostite has been developed. The macro- and micro-network structures seem to be parallel in a given series, *i.e.*, irons of coarse macro-network pattern show also the coarse micro-pattern. It is shown that the differences between the hardened structures of deep- and shallow-hardening cast irons are associated with wide differences in the austenitic transformation rates. The fine-grained, shallow-hardening irons transform considerably faster at 1000° F. than do the coarse-grained, deep-hardening types. In general, the rate of transformation of austenite at 1000° F. is much slower than that for plain carbon steel.

A Thermodynamic Explanation of Reactions at the Austenite-Martensite Transformation. C. H. Johansson. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Nov., pp. 241–251). The relationship between temperature and concentration and the free energy of γ- and α-irons containing imbedded carbon atoms is deduced by consideration of the thermodynamics of the iron-carbon alloys between 300° K. and 1800° K. and with the carbon atoms variously situated in the lattice. The heat content, entropy and free energy of the iron-carbon alloys are discussed, the numerical determination of the free energy is demonstrated, and the processes occurring on the breakdown of austenite are examined in the light of the above considerations.

On a New Phase in the Iron-Zinc System. J. Schramm. (Zeitschrift für Metallkunde, 1937, vol. 29, July, pp. 222–223). The author describes X-ray, thermal, magnetic and microscopic investigations on a new phase containing 6% of zinc in the zinc-iron system. This phase (ξ) is formed at 530° C. as a result of a peritectic transformation in the δ phase.

CORROSION OF IRON AND STEEL

(Continued from pp. 42 A–43 A)

White Rust Formation on Galvanised Wire. E. H. Schulz. (Wire Industry, 1937, vol. 4, Aug., pp. 447–449). An English translation of an article which originally appeared in Stahl und Eisen, 1930, vol. 50, Mar. 20, pp. 360–362. The white bloom on galvanised articles is due to the action of water vapour and carbon dioxide and may occur where ventilation is insufficient and condensation frequent. The purity of the zinc coating has no effect on the phenomenon, which is to be distinguished from that resulting from attack by sea-water; the white bloom formed in this case is of different composition.

Reactions of Binary Alloys. Part I. C. Goria and G. Venturello. (Gazzetta Chimica Italiana, 1937, vol. 67, Aug., pp. 487–501). After reviewing briefly the results of previous researches by other investigators on the reactions of alloys with gases and mixtures of gases, the authors describe the experimental methods they adopted to determine the results of the interaction of steam and various binary alloys at various temperatures. The influence of varying the proportions of the components of the alloys was studied, and the degree of attack on the specimen was determined by recording its change of weight and by microscopic examination. Among the alloys investigated were those of the iron-aluminium system containing between 5·0 and 89·2% of aluminium, which were caused to react with steam at 600° C. and 800° C.

The Behaviour of Metallic Materials Under Stress by Fluid Impact. M. Vater. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Nov. 6, pp. 1305–1311). Previous investigations on cavitation and the effects of the impact of drops of liquid on metals, together with observations drawn from the erosion occurring in turbines, led in general to the conclusion that the erosion processes resulted from the impact of minute drops of liquid. Since such investigations were concerned mostly with liquids at high velocity, some justification exists for this conclusion. The author points out the limitations of the technique involved in these testing methods, and describes a series of experiments designed to indicate the influence of naturally-occurring and fabricated cavities, pores and surface discontinuities. Pore-free test-pieces offer greater resistance to fluid impact than specimens in which even the smallest irregularities of this type occur; it is shown that the erosion resulting from water impact is due to the alternating stress to which such impact gives rise. The resistance to fatigue under fluid impact was determined for various hard steels and cast steels by observation of the Wöhler lines. Carbon steels, low-alloy steels and cast steels are shown to give a "fatigue range" of 20–25 m.

per sec., with an 8-mm. water jet and $2{\cdot}5 \times 10^6$ impacts. In the case of materials offering greater chemical resistance to soft water, the value obtained is greater. It is further indicated that not only must the "fatigue range" be taken into account when estimating the resistance of a material to water impact, but also the progress of the Wöhler lines. The mean "fatigue range" under the influence of soft-water impact in the case of steels and cast steels is shown to be related to the tensile strength and Brinell hardness in a similar manner to the "fatigue range" deduced from alternating-bend or rotary-bend tests carried out with the specimen subjected simultaneously to the action of soft water. In practice, the impact effect of the liquid is accompanied by effects due to the corrosive nature of commercial fluids.

ANALYSIS

Electrolysis with a Mercury Cathode for the Analysis of Ferrous Materials. Determination of Total Aluminium in Steel. J. Morsing. (Statens Provningsanstalt, Stockholm, 1937, Meddelande 76). A description is given of a simple device for the electrolysis with a mercury cathode, which has for some years been used by the Government Testing Institute, Stockholm, and has proved suitable for removing up to 10 g. of iron in the determination of some minor constituents of ferrous materials, such as aluminium, titanium, vanadium, zirconium, columbium, &c. The electrolysis is carried out in tall 400-c.c. Jena beakers at a current density of 0·16 to 0·20 amp. per sq. cm. During the electrolysis the mercury cathode is stirred with a glass stirrer that rotates in the mercury. The anode, consisting of a coiled platinum wire sealed in a glass tube, the contact to the cathode (a piece of platinum wire, also sealed in a narrow glass tube) and the stirrer are fixed in a convenient bakelite holder. After the electrolysis the mercury is purified by treatment with dilute sulphuric acid containing ammonium persulphate. On being vigorously stirred the amalgamated metals easily redissolve in a few minutes. Details are given of the determination of total aluminium in steels by the application of electrolysis for removing the bulk of the iron, chromium, nickel, &c., from the samples.

Apparatus for the Rapid Determination of Carbon in Steel and Pig Iron. H. J. van Royen and H. Greive. (Stahl und Eisen, 1937, vol. 57, Oct. 21, pp. 1201–1202). An absorption apparatus for total-carbon estimation employing asbestos soaked in sodium hydroxide for the removal of carbon dioxide is described. It is claimed that absorption is completed in a single unit and that it is not necessary to employ several successive absorption vessels.

On the Determination of Small Amounts of Carbon in Steel. F. Willems. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 183–184). A method of determining carbon by combustion is described in which, after the absorption of the carbon dioxide in barium hydroxide under controlled conditions, the barium carbonate is filtered off and the barium in it is titrated with sulphuric acid. The carbon is calculated from the barium content obtained. The apparatus employed is fully described.

The Determination of Molybdenum in Steels by Means of the Pulfrich Photometer. A. Eder. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Oct., pp. 185–187). A modified method of estimating molybdenum in steels colorimetrically by means of potassium thiocyanate and stannous chloride is described, the resulting reddish-brown solution being compared with a suitable standard

in the Pulfrich photometer. The influence of other elements is discussed.

Estimation of Silicon in Steel. G. Charpy. (Comptes Rendus : Génie Civil, 1937, vol. 111, Oct. 9, pp. 313–314). The technique of obtaining an accurate value for the silicon content of a steel by estimating the silicon in the residue of the material after treatment with acid is discussed.

Contribution to the Determination of Hydrogen in Steels. O. Meyer and F. Willems. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Nov., pp. 259–261). A series of comparative tests on acid and basic carbon steels and high-chromium and high nickel-chromium steels indicated that heating *in vacuo* in the carbon-resistor furnace at about 1625° C. for approximately 15 min. yielded accurate values for the hydrogen content of the metal.

Slag Inclusions in Steel. H. Diergarten. (Metal Progress, 1937, vol. 32, Sept., pp. 269–271). The author outlines the technique of slag-inclusion determination as conducted at the United Ball Bearing Co. (SKF). The particular significance of inclusion control in ball bearings is discussed, and notes are included on typical inclusions in open-hearth steels, electric steels, and in steels melted in the high-frequency induction furnace. A chart is given illustrating standards for size and frequency of slag inclusions in steel.

On Various Spectrum-Analysis Researches for Industrial Laboratories. R. Ramb. (Metallwirtschaft, 1937, vol. 16, Oct. 22, pp. 1102–1107). Results are presented of an investigation of the quantitative determination of aluminium in an aluminium-iron alloy for resistance purposes; chemical and spectral results are compared for another series of aluminium-iron alloys containing about 3·7–6·23% of the former metal. A comparison is also made between the results of chemical and spectroscopic methods for the determination of silicon in steel.

Progress in the Technique of Spectrum Analysis. W. Gerlach and W. Rollwagen. (Metallwirtschaft, 1937, vol. 16, Oct. 22, pp. 1083–1094). Recent practice with regard to qualitative, semi-quantitative and quantitative spectrum analysis is discussed. Different means of excitation are examined and the technique for certain solutions and solid salts and metals is reviewed. It is pointed out that of the non-metals sulphur has only been determined with any degree of accuracy by the use of a Geissler tube.

The Status of Emission-Spectrum Analysis. W. Seith. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 252–256). The author describes briefly the principles of spectrum analysis and techniques appropriate for various elements and for various conditions. Seventy-five elements may be detected spectroscopically; the remainder are only of minor interest in connection with metallurgy. Chemical and spectroscopic methods of analysis are compared, and the accuracy of and sources of error in the latter

method are discussed. The determination of silicon in iron is referred to.

The Direct Photo-Electric Determination of Elements in the Flame. J. Heyes. (Angewandte Chemie, 1937, vol. 50, Nov. 20, pp. 871–874). After a brief discussion on the theory of spectroscopic analysis the author describes experiments carried out with a compressed-air/acetylene exciting flame on the direct photo-electric determination of various metals including chromium and manganese. The technique and the apparatus employed and the accuracy of the determinations are discussed.

Moisture Determination in Gas. K. Guthmann and G. Schumacher. (Stahl und Eisen, 1937, vol. 57, Oct. 14, pp. 1177–1178). It was found that the determination of moisture contents below 10 g. per cu.m. in coke-oven and other commercial gases by absorption in calcium chloride gave low results. Silica gel was found to absorb hydrocarbons, which were also removed by sulphuric acid with decomposition. Results are presented for absorption by phosphorus pentoxide and ferric chloride in addition to calcium chloride, and the limitations of each discussed.

British Standard Methods for the Sampling and Analysis of Coal and Coke for Performance and Efficiency Tests on Industrial Plant. (British Standards Institution, No. 735–1937).

BOOK NOTICES

(Continued from pp. 44 A–48 A)

DESCH, C. H. "*Metallography.*" Fourth ed. (Textbooks of Physical Chemistry). 8vo. pp. viii + 402. Illustrated. London, New York, and Toronto, 1937: Longmans, Green and Co. (Price 21*s.*)

In reviewing a new edition of a book that has been a standard work for a quarter of a century, the question arises whether it is best to assume acquaintance with the earlier editions, and deal with the new one as an advance on these, or to treat the edition as a new book. It is difficult to believe that there are any metallurgists in Britain who have not read and occasionally consulted Desch's "Metallography," but it does not follow that its contents are so fresh in their minds that a few comments on the changes introduced in the new edition will suffice to give an adequate impression of what it contains. The most obvious differences between the new edition and the earlier ones are the inclusion of two chapters on X-rays by G. D. Preston and the omission of the list of systems which was a valuable appendix. Otherwise the general structure of the book is the same. Several alterations have, however, been made in the arrangement of the chapters, and the text has been drastically revised, to the extent in some cases of rewriting whole chapters. With so much information now available there must have been a great temptation to increase the magnitude of the book, but the author has wisely resisted this and kept the work within the limits suitable for a student's text-book. Actually the revision and the incorporation of the chapters on X-rays have resulted in an expansion from about 150 to 190 thousand words. Despite its restricted size, the volume covers a very wide field, including equilibrium diagrams and the constituents of alloys, crystallisation and diffusion in the solid, practical thermal analysis, pyrometry and dilatometry, microscopic examination, the physical properties of alloys, electrolytic potential and corrosion, mechanical deformation and its effects, and the metallography of iron and steel and non-ferrous metals. The inclusion of all this within the available space has made it impossible to deal fully with some of the more controversial and intricate subjects, but in view of the great utility of the previous editions, the author has been well advised to keep to the same lines instead of writing another kind of book which might have proved of greater interest to specialists but would have failed to hold its place in the list of students' text-books. As the previous edition has been out of date for some time, the appearance of this new edition will be welcomed, not by students only, but by all others who have been unable to keep up with the progress of the subject as it has been developed in the proceedings of the societies, the reports of State and other laboratories, and in monographs concerned with particular aspects.

J. M. ROBERTSON.

JONES, W. D. "*Principles of Powder Metallurgy. With an Account of Industrial Practice.*" 8vo. pp. xii + 199. Illustrated. London, 1937: Edward Arnold & Co. (Price 15*s.*)

Metallic powders for use in paints have been commercial products for a very long time, but the production of compact metals by the compression and sintering of powders has only recently become of comparatively wide interest. The Wollaston process for platinum, invented early in the nineteenth century, was the first application of the method of compressing and sintering, but no further developments occurred until the demand arose for metallic filaments for electric lamps. At the beginning of the present century the method was applied to the manufacture of osmium filaments, and similar technique was later used in the preparation of tantalum and finally of tungsten filaments. Since then developments have taken place in several directions. The production of sintered or cemented carbides is a direct outcome of the knowledge acquired in the manufacture of filaments, and the oil-less bronze bearing is a unique application of the technique of powder metallurgy. In addition to these specialised applications, however, the method has been adopted as an alternative means of producing metallic articles without melting and casting, and in this way very pure metals, and alloys that cannot be produced by fusion, are being prepared.

Numerous articles dealing with the applications of the powder method have appeared in the technical press, but the principles on which the process depends have not been discussed to any extent in English and American metallurgical publications. In view of the varied and novel applications of powder metallurgy, the interesting principles involved, and the evident prospect of fairly rapid future developments, the appearance of a book on the subject should be generally welcomed. The present work is exactly what is wanted at the present time, and it deals simply and effectively with the general aspects of the subject. It may be divided roughly into four parts. The first, consisting of two chapters, is devoted to the consideration of the phenomenon of sintering, and the second, consisting of one chapter, deals with the physical properties of sintered metal compacts and the influence of the method of preparation. The third part (two chapters) is concerned with the industrial applications, *i.e.*, platinum, carbonyl iron, nickel, nickel-iron alloys, bronze bearings, chromium, tungsten and cemented carbides. Finally, in the last chapter the manufacture, properties and testing of metal powders are described.

J. M. ROBERTSON.

WARNOCK, F. V. "*Strength of Materials. A Textbook Covering the Syllabuses of the B.Sc.(Eng.), I.C.E. and I.Mech.E. Examinations in this Subject.*" Third ed. 8vo. pp. ix + 389. Illustrated. London, 1937: Sir Isaac Pitman & Sons, Ltd. (Price 10*s.* 6*d.*)

This is the third edition of a book which was first published in 1927 with the object of assisting students working for the degrees of the University of London and the final examinations of the various professional engineering institutions. Its interest is not, however, specifically confined to those, for the ground covered makes it a suitable text-book for students in other universities and colleges and a useful book for practical engineers. The general scope is similar to that of other books on the same subject. Thus the first two chapters deal respectively with simple and compound stresses and strains, the third

chapter deals with the simple mechanical properties of metals, and the remainder of the book, with the exception of the last chapter, is concerned with stress and strain in cylinders, beams, shafts, columns, struts and moving parts. The last chapter, which occupies 66 pages, is devoted to a consideration of testing and testing machines, and includes descriptions of testing in tension, compression, shear and torsion, the determination of hardness and of endurance properties, as well as a brief account of the effect of composition, heat treatment, temperature, &c., on the tensile properties of steel. The book contains a large number of worked examples taken from recent examination papers of the University of London and the Institutions of Civil and Mechanical Engineers, and at the end of each chapter a number of exercises taken from the same sources is given. In preparing this third edition the opportunity has been taken of revising the text to a certain extent, of including new matter, and of adding to the number of worked examples.

J. M. ROBERTSON.

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REFRACTORY MATERIALS

(Continued from pp. 52 A–53 A)

The Permanent Expansion of Silica Bricks. Part I. A. E. Dodd. (Transactions of the Ceramic Society, 1937, vol. 36, Nov., pp. 466–472). Experiments carried out on the permanent expansion of silica bricks by standard methods indicate that the standard test is not sufficiently drastic to ensure complete quartz conversion in samples of high specific gravity. Samples of the same specific gravity may yield different results in a test at 1450° C. of 2 hr. duration; any brick with a specific gravity above 2·38 will give a permanent expansion above 0·5% if heated for a sufficiently long period above 1400° C.; if the specific gravity is above 2·36 and 2 hr. heating at 1450° C. produces an expansion of less than 0·5%, a modified test at 1500° C. for 5 hr. is suggested. The increases in porosity shown by eighteen out of twenty samples on refiring suggest that different results may be obtained in service when the bricks are subjected to a load.

The Permanent Expansion of Silica Bricks. Part II. A. E. Dodd. (Transactions of the Ceramic Society, 1937, vol. 36, Nov., pp. 473–484). A permanent expansion-under-load value can be obtained from the normal refractoriness-under-load curve, provided that this curve is corrected for the expansion of the thrust column and the corrected value is then reduced to a percentage basis. Silica bricks of low refractoriness-under-load (below 1650° C.) may accommodate the expansion due to quartz conversion by plastic deformation, but the behaviour under prolonged heating cannot be predicted from the refractoriness-under-load and specific gravity alone. A continuous record of movement of the test-piece under load at high temperatures is valuable; initial expansion has been known to be followed by subsidence and collapse by shear even at 1600° C.; other specimens expand or contract continuously during the 5-hr. test. Certain bricks high in cristobalite exhibit high permanent expansion above 1600° C., this being attributed to an increase in porosity due to recrystallisation of the cristobalite in an expanded form, although this suggestion is purely tentative.

Firestone as a Refractory. H. Rayner. (American Foundrymen's Association: Blast Furnace and Steel Plant, 1937, vol. 25, Sept., pp. 1009–1012). The author discusses the geology and chemistry of firestone, indicates methods for working it into suitable forms for use as a refractory and considers its applications in cupolas, ladles, soaking-pits and electric furnaces.

Selection of Bricks for Blast-Furnaces. A. B. Searle. (Iron and Steel Industry, 1937, vol. 11, Oct., pp. 7–10; Nov., pp. 55–

57). The author discusses at length the conditions encountered by the refractories in a blast-furnace; each zone is considered under a separate heading. The physical properties of the bricks are discussed in relation to the conditions encountered. The shape and sizes of bricks, the lining of the downcomer and dust-catcher, foundations, insulating bricks, faulty construction of linings and present trends are dealt with in turn.

Investigations on Basic Refractories with Particular Reference to their Use in the Lining of Induction Furnaces. C. Booth and W. J. Rees. (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1937, vol. 26, pp. 57–122). Mixtures of dead-burned Grecian magnesite with up to 25% of cordierite have been investigated with a view to improving the spalling resistance of magnesite. It is shown that additions of cordierite lower the firing shrinkage, thermal expansion and refractoriness-under-load "start to fail" temperature, but increase the porosity. The reduction in thermal expansion is not accompanied by any appreciable increase in the resistance to thermal shock. Mixtures of magnesite and cordierite have low resistance to corrosion by basic slag, but mixtures containing less than 15% of cordierite have good resistance to slags high in iron oxide. Microscopical examination shows that reaction takes place between magnesite and cordierite, giving spinel, forsterite and some magnesium aluminium silicate melt. An investigation into the bonding of electrically-fused magnesite suggests that the best bonds are calcium fluoride and calcium orthophosphate. Microscopical examination shows that when fluxes are added to electrically-fused magnesite, a melt is formed, which penetrates along the cleavage planes, and develops a pockilitic structure similar to that of dead-burned magnesite. The effect of increase in moulding pressure on the properties of some electrically-fused magnesite mixtures has been investigated. It is found that increasing the moulding pressure reduces the firing shrinkage, porosity, permeability and thermal sensitivity. Extension of this work shows that by using high moulding pressures and a suitable bond, it is possible to produce "unfired" bricks the properties of which are equal to those of fired bricks. The green strength and refractoriness-under-load values increase considerably with the moulding pressure, whilst the thermal sensitivity and depth of penetration by basic slag are greatly reduced. It is shown that there is a mathematical connection between the moulding pressure and the physical properties of a pressed refractory.

Why and How Insulating Refractories Insulate. W. Trinks. (Industrial Heating, 1937, vol. 4, Oct., pp. 911–914). The author discusses the theory of the heat-insulating properties of insulating refractories, particularly of insulating firebricks, from an elementary mathematical standpoint.

FUEL

(Continued from pp. 54 A–56 A)

Burning of Coal and Coke Treated with Small Quantities of Chemicals. P. Nicholls, W. E. Rice, B. A. Landry and W. T. Reid. (United States Bureau of Mines, 1937, Bulletin No. 404). The authors present a detailed report on investigations on the effect of small additions of various chemicals upon the combustion characteristics of various coals. Tabular data are presented, and it is concluded that in small amounts such additions have no appreciably beneficial effect on combustion. (*See* following abstract).

Chemical Treatment of Coal and Coke. P. Nicholls. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 848). The author summarises the results of an investigation into the effect of small quantities of various chemicals on the burning properties of various coals. Quantities between 4 and 40 lb. per ton were employed and their effect on caking, reactivity, clinkering, sulphur content and other properties was studied. The results obtained do not on the whole favour such treatment. (*See* preceding abstract).

Fuel at the Ford Works. (Fuel Economist, 1937, vol. 12, July, pp. 345–349). A brief account is given of the various departments of the works of the Ford Motor Co. at Dagenham, with special reference to fuel and its efficient utilisation.

The Appleby Power House. (Iron and Steel Industry, 1937, vol. 11, Oct., pp. 11–12). An account is given of a 6250-kW., 6600-V., 3-phase, 50-cycle Parsons steam turbo-alternator recently installed at the Appleby works of the Appleby-Frodingham Steel Co., Ltd. Steam is supplied to the turbine at 350 lb. per sq in. and superheated to a temperature of 775° F.

Modern Steam Turbines in Steel Mills. A. G. Darling. (Iron and Steel Engineer, 1937, vol. 14, Aug., pp. 39–47). The author describes the developments in the design of turbine-generators for the steel industry during the last ten years, the advances incorporated in new plant and some of the advantages obtained in such new plant.

Turbine Developments. C. B. Campbell. (Iron and Steel Engineer, 1937, vol. 14, Sept., pp. 48–56). The author discusses developments in the turbine with special reference to its applications in the steel industry. After considering the use of increasingly higher pressures and temperatures and the limitations imposed on this development by the mechanical properties of metals at high temperatures, the use of alloy steels is briefly considered. The

development of the high-speed single-cylinder unit and of superimposed turbines is discussed, and in conclusion special problems in connection with the application of steam turbines to steel-mill power plants are dealt with.

Steam Generation from Gas Engine Exhaust in America. T. A. Lewis. (Iron and Steel Engineer, 1937, vol. 14, Sept., pp. 40–45). The author examines the mechanics and economics of systems designed to utilise the heat from a gas-engine exhaust to raise steam for heating and power. In particular the practice of the Bethlehem Steel Co. is described, and some comparison is made with European developments. Tabular and graphical data are presented, and reference is made to binary cycles such as mercury-steam and diphenyloxide-steam. The simplicity of the waste-heat boiler is emphasised.

Some High Lights in the Use of Electricity in Steel Mills. F. Fox. (Electrical Engineering, 1937, vol. 56, Sept., pp. 1115–1123). The tendency of the American steel industry to employ electric power is increasing, and while two-thirds of the power used is produced on the plant, a trend exists for the purchase of power to increase in volume. Diesel-electric locomotives are being widely adopted. Direct-current motors are being used for main-roll drives and synchronous motors are gaining favour, while reversing drives are finding interesting uses. Main-roll drives tend to be subdivided, and reduction gears and mill pinions are being combined in a single unit. New types of bearings are affecting power requirements. The concentration of direct-current power associated with main-roll drives of wide-strip mills introduces problems connected with the breaking-capacity of circuit breakers and the strength of bus-bar installations. Small induction motors are being widely used for auxiliary drives, and in the field of gas cleaning, electrostatic precipitators are finding increased acceptance. Electric melting furnaces supply a small but growing increment of the total steel production, and new designs are making their appearance for which new and extended uses are being found.

Steel Production in South Africa. N. M. Hoogenhout. (Electrical Review, 1937, vol. 121, Oct. 15, pp. 517–520). An account is given of the electrical plant at the Pretoria works of the South African Iron and Steel Corporation.

Fuel Control in the Iron and Steel Industry. M. Koopman. (Newport and District Metallurgical Society, Nov. 6, 1937: Iron and Coal Trades Review, 1937, vol. 135, Nov. 19, pp. 837–838; Nov. 26, pp. 885–886). The author discusses in relation to the iron and steel industry the fuel supply and its continuity, the co-ordination of the supply and utilisation of fuel, the establishment of performance standards in connection with fuel and heat-consuming units, the rectification of such units to increase the thermal efficiency, the inefficiency of reheating furnaces and furnace standards, instrument control, and new designs in soaking pits.

Statistical Interpretation of Laboratory Coal Tests and Sampling Methods. G. B. Gould. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 849). The author discusses the significance of tolerances as applied to the measurement of coal quality.

The Colloidal Structure of Coal. (Fuel in Science and Practice, 1937, vol. 16, Oct., pp. 288–303). A translation into English of an article by G. Agde and R. Hubertus which appeared originally in Braunkohlenarchiv, 1936, vol. 46. The authors examine the colloid-chemistry of coal to determine the factors governing certain phenomena observed in the coking, briquetting, hydrogenation and other methods of coal treatment. The results of a systematic research are presented. Various types of coal were investigated, the so-called "micron" mill of Fischer, Peters and Cremer being employed to crush the samples.

Some Physical Evidences of Development of Rank in Vitrain. L. C. McCabe. (Fuel in Science and Practice, 1937, vol. 16, Sept., pp. 267–280; Oct., pp. 309–316). To determine a physical basis for the differentiation of rank in coal the author examined the physical properties of vitrain from a number of Illinois coals. Electrical conductivity and X-ray-diffraction determinations were made, together with those of the angle of polarisation and of the index of refraction. The value of each of these properties as a measure of rank is discussed.

Relationship Between the Microstructure of Coals and Pure Coal. F. L. Kühlwein. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 221–228). The author discusses the preparation of coals of low ash content and considers the distribution of foreign matter giving rise to ash in the microconstituents of the coal. Methods of removing constituents characterised by high impurity contents are examined at length. Tabular and graphical data are presented for various types of coal.

Analyses of Colorado Coals. (United States Bureau of Mines, 1937, Technical Paper No. 574). A series of eight papers is presented, dealing with the geology, mining, distribution and use, sampling and analyses of Colorado coals.

Microscopic Features of Certain Alberta Coals. I. W. Jones. (Canadian Journal of Research: Fuel in Science and Practice, 1937, vol. 16, July, pp. 208–217; Aug., pp. 224–230). The author describes the results of a microscopical investigation of Alberta coals. Typical structures are discussed; it has not proved feasible to correlate the Alberta seams on the basis of their microscopical characteristics. The palæobotanical value of this method of investigation is stressed, and the scope of further researches indicated.

The New Washery at Orgreave Colliery. (Colliery Guardian, 1937, vol. 155, Nov. 5, pp. 841–844). An account is presented of

the construction and operation of the Norton washing plant at the Orgreave Colliery, near Rotherham, of the United Steel Companies. The plant has a capacity of at least 200 tons per hr.

Co-ordination of Theories of Gravity Separation. A. A. Hirst. (Transactions of the Institution of Mining Engineers, 1937, vol. 94, Oct., pp. 93–109). A mathematical study is presented of fundamental principles involved in the cleaning of coal by mechanical methods. The paper is mainly concerned with the physics and mechanics of powder masses.

Economics of Preparing Coal for Steam Generation. H. F. Hebley. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 847). The author discusses the implications of coal cleaning and the effect of such treatment on the characteristics of the coal during combustion and on the volatile products and incombustible residues.

The Separation Process in the Rheolaveur. R. Sembol. (Glückauf, 1937, vol. 73, Oct. 23, pp. 969–977; Oct. 30, pp. 993–997). The author presents the results of an investigation of the separation process in a Rheolaveur. The material treated in the plant upon which the research was undertaken was fat coal. The individual stages of the separation phenomenon are examined in detail and certain conclusions are drawn regarding the application of the results obtained to commercial practice.

Segregation in the Handling of Coal. D. R. Mitchell. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 846). Many of the difficulties encountered in the preparation of coal for the market, in sampling coal and in the utilisation of coal are caused by size segregation and density segregation. The mechanism of these processes, as deduced from experimental evidence, is described and means of preventing their occurrence are discussed.

The Flocculation of Coal Slurries. E. Tomalin. (Journal of the Society of Chemical Industry, 1937, vol. 56, Oct., pp. 384T–388T). From a determination of sedimentation rates under an electrical potential difference and in the presence of cataphoretic starch it was deduced that the majority of slurry particles possessed no intrinsic electrostatic charge; the action of electrolytes is confined apparently to the flocculation of particles of colloidal and semi-colloidal size. Hydrophilic colloids such as starch and gelatin flocculate particles of all sizes, the smaller particles by colloidal action and the large particles by a mechanism still being investigated.

Recent Experiences in the Drying of Coal by the Method of Professor Fleissner. H. Klein. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 217–221). The results of various experiments involving modifications of the Fleissner method for drying coal are briefly reviewed and discussed. The use of various chemical additions

to assist the drying process is referred to, together with the influence of the steam pressure employed on the drying of various types of coal and their behaviour during heating under pressure. The corrosion and wear of the drying equipment are also considered.

Pulverised Fuel Firing Without a Pulveriser. H. D. Tollemache. (Journal of the Institution of Production Engineers, 1937, vol. 16, Nov., pp. 579–588). After discussing the physical properties of pulverised coal and the pulverising processes employed for producing it, the author examines in more detail certain disadvantages attaching to pulverising units operated in conjunction with the consumer's plant. The production and marketing of pulverised coal in bulk are then dealt with and the advantages of such a system are considered.

The Influence of Particle Size in Processes of Fuel Technology. P. O. Rosin. (Journal of the Institute of Fuel, 1937, vol. 11, Oct., pp. 26–41). The author discusses the physics and mechanics of pulverised coal from the standpoint of the influence of particle size on the geometrical and mechanical relationship of the properties of the particle to those of the pulverised fuel in bulk, on the aerodynamic properties of the fuel, and on its thermal and chemical reactivity.

The Decomposition of Pyrites during the Laboratory Carbonisation of a Durham Coking Coal. W. S. Patterson and W. J. Metcalfe. (Journal of the Society of Chemical Industry, 1937, vol. 56, Oct., pp. 388T–391T). During the carbonisation of a Durham coking coal containing added pyrites the decomposition of the pyrites commences at about 300° C. and the rate increases rapidly with rise of temperature, stable conditions being attained in 2 hr. at 500° C. and in 30 min. at 600° C. After 4 hr. carbonising at 500° C. and in a shorter time at higher temperatures, the composition of the sulphur compounds (derived from pyrites) in the coke remains almost constant. Both calcium sulphate and pyrites react with the coke principally in the early stages of carbonisation.

The Carbonisation Process. H. L. Riley. (Gas World, 1937, vol. 107, Oct. 2, Coking Section, pp. 12–17). The author describes the structure and crystallographic characteristics of "amorphous" carbon, and in the light of conclusions in this regard considers the structures of cokes. The chemistry of the carbonisation process is next examined, followed by a more detailed consideration of the alterations in the physical properties of materials undergoing carbonisation. Crystallite growth and the effect of the parent substance on the properties of the resultant carbon are discussed with particular reference to coals, and the separation of carbon from the gas phase is also dealt with.

Production of Shaped Coke. D. Brownlie. (Fuel Economist, 1937, vol. 12, Sept., pp. 417–418, 420). The author describes briefly the production of so-called shaped coke by special low-temperature carbonisation processes in Germany. The use of

collapsible-walled retorts is described, and particular consideration is given to the Berg process for both coking and non-coking coals. Plant for operating this process is in course of erection in Cumberland and Westmorland. The utilisation of by-products from this and allied processes is referred to.

The Testing of Coke. C. Rowley. (Bulletin of the British Cast Iron Research Association, 1937, vol. 5, Sept., pp. 42–45). The author describes and appraises the following tests, which were evolved to fulfil the need for an index to the quality of coke: Size analysis of coke; shatter test; critical air blast; wet oxidation test; apparent density; apparent porosity; combustibility test *A*; reactivity test. These tests are in use by various British coke research committees.

Foundry Coke. (Coal Carbonisation, Supplement to Colliery Engineering, 1937, vol. 3, Oct., pp. 163–165; Nov., pp. 170–172, 175). After a detailed critical review of published views on the properties desirable in foundry coke, the conclusions of W. E. Mordecai, Koppers and Homborg are discussed at length. The coking rate and character of coal are also dealt with and the crystallographic nature of coke is discussed. The "order of merit" of coke, carbon and sulphur pick-up and the indication of coke values furnished by laboratory tests are considered.

Standardisation of the Physico-Mechanical Properties of the Donetz Basin Cokes. P. Rubin. (Stal, 1936, No. 10, pp. 1–10). The author describes different methods for testing the physical properties of cokes now in use in the Donetz Basin. (In Russian).

Low-Temperature Coke from Bituminous Coals as Fuel for Portable Gas Producers. R. Lessnig. (Glückauf, 1937, vol. 73, Nov. 20, pp. 1053–1059). Experimental results demonstrate the suitability of low-temperature coke from bituminous coal as a fuel for the production of producer gas in portable plant. The material "fires up" rapidly and quickly produces an excellent gas for power purposes. Various types of low-temperature coke have given equally good results, but the screen size of the fuel is somewhat critical. The temperatures and reaction zones in a producer of the type described are also discussed.

The Wet Purification of Coke Oven Gas. The Staatsmijnen-Otto Process. H. A. J. Pieters. (Fuel in Science and Practice, 1937, vol. 16, Nov., pp. 327–333). The author discusses wet processes for the removal of hydrogen sulphide from coal gas and discusses methods of regenerating the absorbent. The Staatsmijnen-Otto processes for the removal of hydrogen sulphide with recovery of free sulphur or thiosulphate and the recovery of hydrogen cyanide as alkali ferrocyanide are described in detail.

McKee-Feld Scrubbers and Zschokke Disintegrators. F. Egorov. (Stal, 1936, No. 10, pp. 11–25). The author has investigated the operation of the McKee-Feld gas scrubbers and Zschokke disintegrators in the Magnitogorsk Metallurgical Works and describes

the improvements effected to increase their efficiency. (In Russian).

Conditions for the Burning of Blast-Furnace Gas. V. Novakovsky. (Stal, 1936, No. 10, pp. 69–73). The author describes successful methods for the firing of boilers by means of blast-furnace gas. The influence of moisture, gas pressure, excess air and of preheating the gas and air is considered. (In Russian).

Increase in Resistance of a Gas Main during Service. E. Iljin. (Stal, 1936, No. 10, pp. 75–81). The author discusses difficulties encountered with the Rutchenkovo-Stalino gas main due to deposition of naphthalene. (In Russian).

Primary Liquefaction of Coal by Hydrogenation. C. H. Fisher and A. Eisner. (Industrial and Engineering Chemistry, 1937, vol. 29, Aug., pp. 939–945). Pittsburgh bed coal was hydrogenated at 400° C. and under 67 atm. original hydrogen pressure with various dispersion media to determine which medium was the most satisfactory. Tetrahydronaphthalene was proved to be a good dispersion medium and earlier claims in this respect were thus justified. Of others studied, only α-methylnaphthalene and diphenyl were of comparable effectiveness. Several completely aromatic and saturated hydrocarbons such as naphthalene, chrysene, decahydronaphthalene and *n*-hexadecane proved to be poor media. Polar compounds such as phenols and amines proved beneficial when added to the dispersion media.

The Hydrogenation of South African Coals. A. J. Petrick, B. Gaigher and P. Groenewoud. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 38, Sept., pp. 122–144). The authors discuss the theory and practice of the hydrogenation of coal and deal in detail with a series of experiments carried out upon South African coals. A number of factors which may influence the degree of conversion are considered and certain coals are commented upon as being particularly suited to hydrogenation. Comprehensive tabular data are presented.

Experiments on the Continuous Hydrogenation of Coal. Part I.—The Development of a Liquid Phase Plant. N. Booth and F. A. Williams. (Journal of the Institute of Fuel, 1937, vol. 11, Oct., pp. 42–49). The authors describe the construction and operation of an experimental hydrogenation plant for producing the liquid phase characteristic of the first stage of the hydrogenation process. The apparatus is built for handling 1–2 kg. of paste per hour, and was designed to study the effect of variations of conditions not readily determinable on single batches, to compare the behaviour of various types of coal and to produce a supply of oil for experiments on vapour-phase hydrogenation.

British Standard Specification for Fuel Oils for Burners (Petroleum and Shale Oils) Including Methods of Test. (British Standards Institution, No. 742–1937).

PRODUCTION OF IRON

(Continued from p. 57A)

Investigation on the Operation of Large Capacity Blast-Furnaces. M. Pavlov. (Stal, 1936, No. 11, pp. 1–14). The author discusses problems in connection with blast-furnaces with a hearth diameter of 6 m. and more. Twenty-five such furnaces are in operation in the U.S.S.R. and ten more are under construction. The non-uniform working of furnaces of this type claimed by German and American authorities is contested by the author, who describes results obtained in 1934 to 1935 in Magnitogorsk and Kusnetzk. The centre of a 6·5 m. dia. hearth was found to be at a temperature of 1400° to 1500° C., and no indication of unfused material was found. With an initial blast pressure of 1100 mm. the gas pressure at the tuyeres was 950 mm. and at the axis of the hearth 830 mm.; thus the blast penetrated throughout the whole cross-section of the hearth. The oxidising zone extended for a depth of 600 mm. from the tuyeres and in this area the maximum concentration of carbon dioxide (10%) was found. The carbon monoxide concentration did not exceed 40% at the centre of the hearth, which must thus be reached by the air stream. At tuyere level the slags contained 33% of ferrous oxide as against 1·0% in the final slag. The metal contained much silicon (3%) and manganese; intense reduction of ferrous oxide by both manganese and silicon occurred between the tuyere level and the slag notch. The hearths of these large furnaces are thus both sufficiently hot and sufficiently supplied with blast. Irregularities in the shaft were traced to non-uniform distribution of the charge due to faulty operation of the McKee distributor; this lead to non-uniform temperature distribution and to disturbaince of the gas stream in the shaft. The author does not agree with the use of large furnaces of oval cross-section; those still in operation in the Urals have acquired a circular cross-section in use due to unequal wear of the brickwork. (In Russian).

Desulphurising and Refining Blast-Furnace Iron with Sodium Carbonate. (Metallurgia, 1937, vol. 16, Oct., pp. 217–218). After a preliminary discussion on the uses of sodium carbonate for the desulphurisation of cast iron, refined pig iron and converter castings, the methods employed being briefly described, the desulphurisation of basic blast-furnace iron is referred to, followed by an account of the acid process for blast furnaces. In this process the maximum output with the minimum coke consumption is aimed at, and the desulphurisation is carried out in the ladle. The process was first operated at the Corby works of Messrs. Stewarts and Lloyds, Ltd. The modifications required in the conventional

burdening of the blast-furnace are discussed and the technique of operating the desulphurisation process is examined. The economies effected in operation costs by the procedure are briefly mentioned.

An Experimental Blast-Furnace Charge Using "Thermo-Anthracite." G. Balla. (Stal, 1936, No. 10, pp. 26–32). At the Sulino Works in 1935 an experiment was carried out on the smelting of Krivoi Rog iron ore using thermo-anthracite as fuel. Thermo-anthracite is produced by heating raw anthracite to 900° C. to remove the moisture and part of the sulphur and hydrogen. The effect of the heat treatment is to change the structure of the material and to increase its burning velocity. Thermo-anthracite is stated to be better than coke from the point of view of its calorific value and its ash and sulphur contents. In the thermal treatment of the anthracite the CO_2/CO ratio in the gases increases from 1·57 to 3·10, indicating an increase in free carbon. The blast-furnace operations were carried out with varying quantities of the thermo-anthracite added to the coke charge. The results indicate that 50% or more of thermo-anthracite added to the coke charge provides an excellent fuel for blast-furnace operation. (In Russian).

Smelting Ores in the Electric Furnace. R. S. Dean and M. W. von Bernewitz. (United States Bureau of Mines, 1937, Oct., Information Circular No. 6955). The paper surveys the technical and economic changes that have occurred during recent years in the electric smelting of metallic ores. Whilst dealing primarily with the working up of non-ferrous ores, the paper includes a section devoted to a study of the electrometallurgy of iron, manganese and chromium. A brief historical account is given of the development of the electric smelting of iron, reference being made to the earliest known attempt to smelt iron electrically carried out in Italy in 1898. The electrical smelting of iron ore in Norway is dealt with at length. The production of ferro-manganese (low-silicon) by high-temperature non-fusion reduction is described and the manufacture of ferro-chromium is briefly noted.

Swedish Iron and Steel Production.—I. D. D. Howat. (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 41–44). An historical account of the development of the Swedish iron industry is followed by geological and topographical data regarding the supplies of iron ore. Plant and plant operating data in connection with concentrating, sintering and electric furnace plant are presented.

Technical and Commercial Problems of the Iron Industry. E. A. Matejka. (Stahl und Eisen, 1937, vol. 57, Nov. 25, pp. 1323–1325). Problems in connection with the development of low-grade German iron ores and in regard to the controlling of the consumption of imported alloy additions, particularly manganese, are dealt with *inter alia*.

FOUNDRY PRACTICE

(Continued from p. 58A)

Effect of Humidity on Cupola. H. V. Crawford. (Foundry, 1937, vol. 65, Sept., pp. 34–35, 87–88). The author examines in detail the effect of humidity on the operation of the cupola and concludes that its influence may be neglected. The best results may be obtained with the minimum amount of air and coke, the proportions of which are held as constant as possible.

Function of Tuyeres in Cupola Control. J. E. Fletcher. (Foundry Trade Journal, 1937, vol. 57, Dec. 2, pp. 432–433). The author examines the function of the tuyeres in cupola control in relation to the balanced-blast cupola. The influence of air fluctuations is considered, and in conclusion the author states that no objection appears to exist against the use of constant-air-weight fans for balanced-blast-cupola service.

Cupola Practice in Textile Engineering Works. J. Jackson. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Dec. 2, pp. 434–436, 442). The author outlines the general principles of cupola working in textile machinery-making works. The cupolas and auxiliary equipment, operation schedules, lining charging and patching, annealing plant and technique, and costing are dealt with.

High Duty Iron. Some Experiments with the Rocking Arc Furnace. B. MacDougall. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Nov. 25, pp. 407–411, 412). The author describes the results of an investigation of the conditions governing the production in the electric furnace of plain and alloy cast irons possessing high machinability and ultimate strength, high resistance to impact and to wear, high resistance to volume changes and distortion under the influence of heat, and maximum soundness. The furnace used had a rated capacity of 350 lb. of cold charge and was of the rocking arc type consuming 125 kW. The effect of superheating ordinary cupola irons in the electric furnace is discussed, together with the properties of low-carbon and synthetic unalloyed irons. Synthetic cast irons containing nickel, molybdenum, separately or together, are also dealt with. Tabular and graphical data are presented.

Developments in the Production of Malleable Castings.—IX. Annealing Furnaces. H. H. Shepherd. (Iron and Steel Industry, 1937, vol. 10, Sept., pp. 621–624; vol. 11, Oct., pp. 35–38). The author discusses briefly the short-cycle annealing process, and then describes the essential features of annealing ovens. Older practice is summarised, and the relative merits of coal, pulverised coal, coal gas and oil fuel are examined, the second being considered later

in greater detail. The development of the tunnel oven is described. A modified annealing practice employed in America is also dealt with. The heat treatment of malleable cast iron is discussed, the effect on the mechanical properties of the material being examined. Graphitisation and the effect of retarding elements are treated at some length. The production of fine pearlite and the composition and properties of "Promal" and "Z" metals—proprietary types of malleable iron of American origin—are also referred to.

Trends of Continental Steelfoundry Practice. P. C. Fassotte. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Nov. 18, pp. 389–391). The divergent practices in French, Belgian and German steel foundries are discussed and the reasons for this difference considered. Phosphorus control, the slow development of the soda-ash process, the use of arc and induction furnaces and the somewhat unusual application of a special duplexing process are dealt with. The testing and finishing of castings are also discussed.

The Steel Foundry. J. Tonge. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Nov. 18, pp. 399–400). The author discusses foundry problems in connection with the production of iron and steel castings, examines in detail the difficulties encountered in the making of steel and describes the Stock oil-fired converter, the production of steel in electric furnaces, and the surface finishing and mechanical testing of castings.

Treatment of Castings after Casting. H. Herdman. (Foundry Trade Journal, 1937, vol. 57, Nov. 18, pp. 397–398). After discussing the elimination of wasteful handling in the foundry, the author deals with the use of sandblasting and pneumatic tools for cleaning and fettling. The dressing of steel castings is considered under a separate head. Electric and oxy-acetylene welding processes are dealt with and, in conclusion, means of reducing fettling costs are studied.

Some Notes on the Properties of Chilled Metallic Shot and Grit Used in Sand-Blasting. J. E. Hurst. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Dec. 9, pp. 447–448, 450; Dec. 16, pp. 474–476). The author discusses the composition, physical and mechanical properties, and grain size and shape of steel shot and grit used for abrasive purposes. The microstructure and hardness characteristics of the material are also examined. The performance of the grit in service, nozzle wear and service life are critically discussed.

Malleable Foundry Maintains Close Control of Cores. E. Bremer. (Foundry, 1937, vol. 65, Sept., pp. 24–26, 69–70). The preparation of the synthetic sand used in the Saginaw Malleable Iron Division of General Motors Corp., Saginaw, Michigan, is described. Gas-fired kilns with automatic temperature control are used for drying the sand, which is compounded on a core-sand base. The tests carried out on the sand are outlined, and the core-baking equipment

is described at some length. Batch-type recirculating ovens and a vertical continuous oven are used; these are gas-fired also.

A Short Talk on Moulding Sand. H. W. Dietert. (Foundry, 1937, vol. 65, Sept., pp. 31, 82). After a brief reference to the physics and chemistry of moulding sand, the author describes in greater detail the relationship between casting defects and the physical properties of the mixture constituting the sand of which the mould is made. Mould hardness is concluded to be largely responsible for defective castings; if too low, swells may be caused, whilst too high a hardness causes scabs and rat tails.

Sea Coal in the Foundry. R. W. Metcalf. (Foundry, 1937, vol. 65, Sept., pp. 58–60). The author discusses the types of coal employed for mould facings and the location of supplies of suitable material for American consumers. Analysis and screening specifications and methods of delivery to the consumer are considered, and finally the author deals with the effect of coal-dust facings and the importance of controlled particle size, and presents the results of tests made upon thin plates cast in moulds faced in various ways.

On the Mixing of Moulding Sands. H. Uhlitzsch. (Giesserei, 1937, vol. 24, Oct. 22, pp. 537–543). The author examines the physical properties of a moulding sand, such as grain-size range, bond, grain shape and grain colour. The expansion and contraction of the material at high temperatures are considered together with methods of controlling these phenomena. Permeability and mechanical strength are next discussed and certain types of failure in sand moulds are dealt with and their origins traced. The effect of correct mixing procedures on the properties of the sand is considered and their application to practice is discussed.

The Use of Oil Bonded Sands in the Modern Foundry. F. Moss. (Bureau of Steel Manufacturers of Australia, 1937, vol. 1, No. 10, Aug.). The author discusses recent developments in the use of oil-bonded sand for foundry use, the advantages to be gained by the use of such sand and the main conditions which must be fulfilled by oil-bonded cores and moulds. Experiments on variously bonded sands are described and the results are compared. The physical properties of the moulded sand and baked cores are briefly dealt with, together with the costs entailed in moulding.

The Classification of Foundry Sands. T. R. Walker. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Nov. 25, pp. 419–420). The author deals with the necessity for classifying foundry sands into groups exhibiting a limited and related range of properties. A discussion on the properties of the sands is followed by a simplified classification in which the number of properties specified is reduced to a minimum. The importance of grain shape is also considered.

Rotary-Kiln Driers for Foundries. R. Liebetanz. (Giesserei, 1937, vol. 24, Oct. 22, p. 544). The author describes the construction and mode of operation of the latest type of rotary sand drier.

The kiln is connected direct to a furnace burning low-grade fuel and fitted with mechanically-operated rabbles in order to facilitate controlled combustion.

Scrap Grinding Wheels used as Foundry Refractories. W. H. Salmon. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Dec. 2, pp. 427–428). After discussing the classes of scrap abrasive available, the author considers the use of silicon carbide for the making of mouldable chills, and compares the results obtained with those obtained with metallic chills and chills moulded from emery and silica sand. Further applications are for special hard facings and for mould dressings. The repair of furnace linings is also dealt with, high-alumina abrasives being specially suitable for this purpose in the case of high-frequency furnaces.

Examples of Practical Moulding. F. G. Butters. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Dec. 9, pp. 451–452). After a preliminary discussion on moulding sands and patterns, the author outlines the preparation of several typical moulds, including one for a lawn-mower frame and others for internal-combustion engine components.

Molding of Chemical Kettles. P. R. Ramp. (Iron Age, 1937, vol. 140, Sept. 30, pp. 22–25). The author outlines the shortcomings of various methods of moulding large chemical-kettle castings and describes in detail a suitable method for producing alloy castings free from the defects found in those produced by some other methods and which seriously affect the life of the vessel.

Compact Foundry Layout Cuts Costs. W. A. Phair. (Iron Age, 1937, vol. 140, Nov. 11, pp. 42–45: Foundry Trade Journal, 1937, vol. 57, Dec. 2, p. 429). A description is given of the foundry division of the Textile Machine Works, Reading, Pa. The foundry is divided into ferrous and non-ferrous sections, the former having the larger output. The account includes a flow sheet indicating the manner in which the necessity for rehandling is reduced to a minimum.

Wasters—Their Cause and Cure.—IV.—Wasters due to Runners and Risers. (Iron and Steel Industry, 1937, vol. 11, Oct., pp. 13–18). Casting failures due to badly placed runners or to wrongly designed runners are discussed. The use and misuse of risers are also considered.

PRODUCTION OF STEEL

(Continued from pp. 59 A–60 A)

Steel Production. J. Gibson. (Structural Engineer, 1937, vol. 15, Oct., pp. 382–396). After a brief account of the extraction of iron from the ore and of the metallography and chemistry of steel, the author discusses in detail the Bessemer and open-hearth processes and the technique and equipment employed in the manufacture of steel by both methods. The basic and acid open-hearth methods are compared.

Thermal Aspects of the Operation of the Open-Hearth Furnace. V. Sokolov. (Stal, 1936, No. 11, pp. 27–33). The author discusses the work of other investigators on heat exchange in the open-hearth furnace and on the influence of luminous and non-luminous flames, the height to the arch of the furnace, the breadth and combustion velocity of the flame, and on the effect of heat loss through the furnace bottom. The heat balance is important and a heat input of $1{\cdot}8–1{\cdot}9 \times 10^5$ cal. per cu. m. per hr. is suggested. The charge should be about 4–4·5 tons per sq. m., and the optimum height to the arch should be approximately 3 m. (In Russian).

The Rational Heating Curve for Open-Hearth Furnace Roofs. N. Loginsky and A. Zurbenko. (Stal, 1936, No. 10, pp. 33–48). The authors criticise the curves suggested by other investigators and present a new curve for the heating of open-hearth furnace roofs. The complete cycle takes from 60 to 70 hr. (for dinas bricks containing 100% tridymite) to 100 hr. (for bricks containing 100% cristobalite). (In Russian).

The Influence of Impurities on the Reactions between Iron Melts, Iron-Manganese Silicates and Solid Silica. F. Körber. (Stahl und Eisen, 1937, vol. 57, Dec. 2, pp. 1349–1355). The author examines the influence of foreign elements upon the equilibria between iron melts, iron-manganese silicates and solid silica. The impurities which are considered are carbon, phosphorus, sulphur and alloying elements in the melt, and lime, alumina and titanium dioxide in the slags. Conclusions are drawn which are of technical importance in connection with the operation of the acid open-hearth process, the oxidation of manganese and silicon by air blast, and with the reactions between molten steel and refractories with which it may come into contact.

An Investigation of Nitrogen in the Arc-Furnace Process. N. Bonthron. (Jernkontorets Annaler, 1937, vol. 121, No. 10, pp. 637–659). The behaviour of nitrogen in the duplex process (basic-Bessemer and arc furnace) was investigated. Basic Bessemer steel contains 0·010–0·015% of nitrogen, and if anthracite is used for carburising in the arc furnace, an increase in this value is noted,

since anthracite itself contains about 1% of nitrogen. By decarburising it is possible to lower the nitrogen content of the bath to the level found in high-grade basic open-hearth steel (approximately 0·005%); the degree of decarburisation required is shown graphically. Owing to nitrogen absorption persisting in the neighbourhood of the electrodes, particularly as it increases when the nitrogen content of the bath as a whole is lowered, the total content of the gas can only with difficulty be reduced below 0·004%. The nitrogen content of basic Bessemer steel could not be reduced by the addition of aluminium. The segregation of nitrogen during freezing was found to be of the same order as that of phosphorus.

Diesel Electric Locomotives in Steel Mill Service. F. H. Craton. (Iron and Steel Engineer, 1937, vol. 14, Aug., pp. 33–37). The author discusses the use of Diesel-electric locomotives in steelworks and demonstrates their value as efficient flexible units, requiring low maintenance costs and operating at low cost.

Rate of Solidification of Rimming Ingots. J. Chipman and C. R. FonDersmith. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 812 : Metals Technology, 1937, vol. 4, No. 7, Oct.). The rate of solidification of rimming ingots has been determined by spilling the liquid contents and measuring the thickness of the solidified wall. Within the grades studied, which were all below 0·10% of carbon, the solidification rate was constant, and for periods of 1 to 30 min. varied thicknesses of frozen metal were obtained ranging from 6·78 to 4·81 in.

Internal Stress due to Cooling in Cylindrical Steel Ingots. T. Hirone. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Sept., pp. 214–235). A new method is presented for the calculation of internal stresses in cylindrical steel ingots. Applied to an ingot of 40 cm. radius, the results of the calculation are as follows : When the steel is assumed to become elastic above the Ar_{13} points, the central portion of the ingot is always in tension, which reaches a maximum just below the transformation; transformations increase the stress in the centre of the ingot. When the temperature at which the steel becomes elastic lies below the transformation point, considerably less internal stress is induced, and in this case the centre of the ingot is generally in compression.

REHEATING FURNACES

Soaking Pits Fired Simultaneously from Two Sides. C. Longenecker. (Blast Furnace and Steel Plant, 1937, vol. 25, Sept., pp. 995–997). The author describes soaking pits recently put into operation at the plant of the Lukens Steel Co., Coatesville, Pa. Oil fuel is employed, the consumption being less than 15 gal. per ton of steel heated when cold ingots are charged. The design of the pits differs from that commonly employed; a recuperator is employed to heat the air, and highly efficient heating is obtained by the location of a burner and an opening into a flue in each of two opposite walls. Rapid uniform heating is achieved, the hot gases coming into contact with all the ingot surfaces. Structural details are discussed at length.

A Modern Soaking Pit. (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 52–54). An account is given of the circular soaking pit or heating furnace and of the advantages which this type is said to possess over the conventional design. Heating is effected by gas burners firing tangentially into the furnace chamber near the bottom of the ingots. A constant gas/air ratio is maintained, thus ensuring a constant atmosphere in the furnace.

Cinderella of the Steel Mills. E. W. Wagenseil. (Steel, 1937, vol. 101, Aug. 16, pp. 48–54). An account is presented of the evolution of the modern soaking-pit. Various types are described and details of structure and control discussed.

Rod Mill Heating Furnaces at Joliet. (Industrial Heating, 1937, vol. 4, Sept., pp. 738–742). A detailed account is presented of the construction and operation of the heating furnaces at the Joliet mills of the American Steel and Wire Co. Billets for the mills are heated in two single-fire side-discharge continuous furnaces each with a capacity of 22–30 tons per hr. and adapted for coke-oven or natural gas or oil firing. (*See also* p. 127 A).

FORGING, STAMPING AND DRAWING

(Continued from pp. 61 A–62 A)

The Design of Dies and Tools for Presswork. N. C. Wilson. (Transactions of the Manchester Association of Engineers, 1936–37, pp. 183–210). The author discusses metallurgical factors in cold-pressing operations, types of presses, tools, special tools, lubricants, and drawing compounds. Specific operations on certain metals are discussed.

Modern Practice in Press Tool Design. G. L. Smith. (Metal Industry, 1937, vol. 51, Dec. 3, pp. 545–550; Dec. 10, pp. 575–580). The author discusses the fundamental principles of press-tool design. The press and its auxiliaries are described in so far as they are of importance in connection with die design. An account of the preliminary stages of tool designing is followed by a consideration of the development of blanks and drawn components. The method of analysing a pressed component into surfaces of revolution and simple bends is dealt with, and a means of determining the behaviour of material in the press is described.

Combination Die for Blanking, Drawing, Piercing and Trimming a Shell. (Machinery, 1937, vol. 51, Dec. 9, pp. 299–301). An account is given of the construction of a combination die for carrying out a series of operations ranging from blanking to trimming on a drawn shell. The sequence of operation is described.

Reducing Die Costs by Using Graphitic Steel. W. G. Kifer, P. Abel and F. R. Bonte. (Machinery, 1937, vol. 51, Dec. 9, pp. 296–299). The authors describe the use of graphitic steels containing 1·5% of carbon and 1·0% of silicon, and, in one type, approximately 0·25% of molybdenum. The heat treatment of the steels is briefly indicated. "Graphsil" for water-hardening and "Graphmo" for oil-hardening are used for dies, and the account describes their application by the Timken Roller Bearing Co.

Cold Finishing Bar Steel. E. J. Kapf. (Wire and Wire Products, 1937, vol. 12, Aug., pp. 419, 422–428). After a brief reference to the history of the cold-drawing process and a note on the similarity of the technique required to that of wire-drawing, the author enumerates and comments upon the various operations involved and the equipment necessary. Heat-treating, pickling, lime coating, pointing, straightening, cutting and inspecting are dealt with, together with turning and polishing operations involved in the production of bars designed for shafting of above $2\frac{7}{8}$ in. in dia. The concentricity, high polish and freedom from strain of such bars are commented on. The mechanical effects of the cold-

drawing process and the suitability of cold-drawn stock for repetition work on automatic screwing machines are dealt with.

Manufacture of High Carbon Wire. G. Henderson. (B.H.P. Review, 1937, vol. 14, Aug., pp. 1–4). The author describes the manufacture of wire with carbon contents of from 0·4 to 0·90% at the works of Rylands Brothers, Newcastle, Australia. The heat treatment, cleaning, baking and drawing processes are discussed together with those of galvanising and annealing. The manufacture of flattened and square spring wire is outlined, and some applications of galvanised wire, spring wire and rope and hawser wires are noted.

Rational Conditions of Drawing of Wires and Bars of Carbon Steel and Alloy Steels. M. I. Vinograd. (Katshestvennaia Stal, 1937, No. 2, pp. 18–24). The author has investigated the drawing of wires of the steels *U*4 (0·45% carbon), *U*12 (1·25% carbon), *ShKh*15 (1·0% carbon, 1·5% chromium), *V*1 (1·15% carbon, 1·0% tungsten) and *R* (0·72% carbon, 4·2% chromium, 18% tungsten), and the drawing of bars of the steels *ShKh*15, *U*10 (1% carbon), *E*3 (0·75 chromium, 3% nickel), *E*4 (0·2% carbon, 0·25% chromium, 3% nickel), *E*8 (0·3% carbon, 1·1% chromium, 3·2% nickel), and *E*10 (0·35% carbon, 1·4% chromium, 3·4% nickel). The temporary resistance and the hardness increase with increasing deformation, at first quickly, then more slowly; the elongation and contraction change in the opposite direction. The number of passes does not affect the mechanical properties (with a given total deformation). The same is true for the velocity of drawing (0·01–4 m. per min.). The effort of drawing increases more slowly than the deformation; it is independent of the type of steel, if all steels compared are treated thermally so as to have nearly the same hardness and a temporary tensile strength of 65–75 kg. per sq. mm. The specific effort and the pressure on the side surface of the die decrease with increasing deformation; it is therefore advisable to use large deformations. (In Russian).

Flash Baking of Wire Rods. K. B. Lewis. (Industrial Heating, 1937, vol. 4, Oct., pp. 885–888). After a preliminary account of the development of the modern baking oven for wire rod, the author describes in detail the construction and operation of the "flash baker" marketed by the Morrison Engineering Co., Cleveland, Ohio. High-velocity air currents and a temperature of 750° F. have reduced baking times from the original period of 24 hr. to about 5 min. Particular attention is paid to the fact that no special precautions are required to prevent the products of combustion from coming into contact with the charge; this is said to be due to the reaction period being so short, and it is claimed that even coke-oven gas may be safely used in the flash baker.

ROLLING-MILL PRACTICE

(Continued from pp. 63A–64A)

Deformation of Metal in the Skew-Roll Tube Rolling Mill. I. Fomichev. (Stal, 1936, No. 11, pp. 45–57). Investigations on the deformation of 275-mm. dia. billets in a Mannesmann rolling mill were carried out by sectioning a partly rolled tube. The wall thickness and the diameter of the bore were measured and the elongations calculated. Torsional effects were estimated by the form assumed by a line drawn on the billet before rolling. Initially longitudinal elongation occurs in the outer layers of the billet, which tends to become hollow at the axis; torsional effects and further effects of displacement of the surface metal increase this tendency. On the mandrel the central layers of the billet are displaced to a greater degree than the exterior layers, and the sense of the torsional effects is reversed and becomes similar to that of the rotation of the rolls. The metal displaced by the widening of the bore is employed chiefly in producing elongation of the tube. The third stage of the process consists in rendering the slightly oval tube circular, the diameter decreasing slightly and the length increasing slightly when this takes place. The author assigns greater importance than previous workers to the influence of the mandrel in the second stage of the process, when it induces the formation of a conical hole even before coming into contact with the billet at the point in question. The deformation by flow which explains this action is considered. (In Russian).

Roll Pressures in Hot Rolling. W. Trinks. (Blast Furnace and Steel Plant, 1937, vol. 25, Sept., pp. 1005–1008, 1012). The author discusses the mathematical derivation of data on the flow resistance of hot steel in connection with roll pressures in hot rolling. Curves from which roll pressures may be determined are presented and it is noted that these yield higher values than those derived from Ekelund's formula.

Electric Gauges Facilitated Rolling Mill Operations. A. S. Burgoyne. (Iron Age, 1937, vol. 140, Nov. 11, pp. 46–49). An account is presented of the "classifier" and "strain" gauges developed from the Pratt and Whitney Electro-Limit continuous gauge. The principle of the machine is described. The classifier is employed for sorting sheet and strip, while the strain gauge is used to determine roll pressures. The advantages accruing from the employment of these instruments are discussed.

General Discussion on Lubrication and Lubricants. (Institution of Mechanical Engineers, Oct., 1937). At a symposium on lubrication and lubricants held by the Institution of Mechanical

Engineers in London on Oct. 13, 14 and 15, 1937, the following papers of metallurgical interest were discussed: Fabric Bearings for Rolling Mills, by H. Rochester; Lubrication of Piston Rings, by C. A. Bouman; Wear of Cylinder and Piston Rings, by H. J. Young; Lubrication in the Cold Pressing of Sheet Steel, by J. C. Arrowsmith; Cutting Fluids, by O. W. Boston; The Characteristics of Gear Lubricants Revealed by the Four-Ball Extreme-Pressure Lubricant Testing Apparatus, by D. Clayton; Lubrication in Wiredrawing, by R. Goodacre; Cutting Fluids and Cooling Oils in Machine Tools, by A. H. Lloyd and H. H. Beeny; The Application of Cutting Fluids, by J. F. Miller; Lubrication in Wiredrawing, by F. C. Thompson; The Lubrication of Wire Ropes, by M. A. Hogan; The Friction of Sliding Metals, by F. P. Bowden; An Experimental Study of Lubrication under Conditions of Extreme Pressure, by J. E. Southcombe, J. H. Wells and J. H. Waters; Heavy-Duty Bearings of Phenolic Plastics, by H. M. Richardson; The Wear of Cast Iron, by J. G. Pearce. (*See* p. 144 A).

Increasing Rolling Mill Output. G. W. Fox. (Sheffield Trades Technical Society, Nov. 17, 1937: Iron and Coal Trades Review, 1937, vol. 135, Dec. 3, pp. 921–922). An account is presented of the cogging, billet and slab mills at the Templeborough Works of the United Steel Companies, Ltd. The mill equipment and the products of the mills are discussed, and the recuperative soaking pits are considered particularly in connection with the increased capacity which they permit. The rolling of special steels is dealt with and reference is made to the elimination of guide-marked billets.

New Continuous Rod Mills, American Steel and Wire Co., at Joliet, Illinois. (Wire and Wire Products, 1937, vol. 12, Aug., pp. 401–405, 448). The continuous rod mill in operation at the Joliet plant of the American Steel and Wire Co. is described. (*See also* Journ. I. and S.I., 1937, No. II., p. 183 A, and this Journ. p. 123 A).

Drives and Control For a Modern Rod Mill. R. H. Wright and B. J. Auburn. (Iron and Steel Engineer, 1937, vol. 14, Oct., pp. 35–37). The authors describe equipment at the Joliet mills of the American Steel and Wire Co. Particular reference is made to the reels upon which the hot finished rod is coiled as it leaves the mill; six reels are provided for each mill. The construction, operation and control of the electric motors driving the reels are discussed in detail.

Uninterrupted Materials Flow Permits Continuous Operation in Wire Mill. (Steel, 1937, vol. 101, Oct. 18, pp. 47–50, 73). The South Chicago Wire Mill of the Republic Steel Corp. is designed to permit a continuous flow of material with the minimum handling other than that required to keep the work moving forward. Automatic or semi-automatic electrical control of handling equipment is provided wherever possible, and may be actuated by the operator either from the floor or from the cabs of cranes. The handling units are described in detail.

Fixing Operation Times in Finishing Shops, Particularly in Rolling Mills for Medium and Heavy Shapes and Sections. C. Hoppe. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 303–306). The author presents an analysis of time studies on operations entailed in the finishing and straightening of medium and heavy shapes and sections produced in the rolling mill.

Gary Sheet and Tin Division Carnegie-Illinois Steel Corporation. (Iron and Steel Engineer, 1937, vol. 14, Sept., pp. 2G–19G). **Gary Sheet and Tinplate Mills of Carnegie-Illinois Steel Corporation.** (Iron and Coal Trades Review, 1937, vol. 135, Dec. 3, pp. 929–933). (*See* p. 14 A).

Heavy Hot Levelling Machines. (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 45–46). The trend of Continental designs in heavy hot-levelling machines is exemplified by an account of machines supplied by Ehrhardt and Sehmer.

Inland's 76″ Continuous Strip Mill. (Iron and Steel Engineer, 1937, vol. 14, Sept., pp. 2I–15I). An account is presented of the plant, layout and production of strip and tin mills of the Inland Steel Co., Indiana Harbor, Indiana, U.S.A. The account includes a plan of the works and tabular data regarding mills, mill drives and outputs. The power supply system is described in detail and sections are devoted to accounts of the annealing and pickling shops.

Tension Measurement and Control in Cold-Strip Mills. C. M. Hathaway and M. Mohler. (Electrical Engineering, 1937, vol. 56, Sept., pp. 1141–1144). A description is given of a tensometer, a device employed for estimating the tension in the strip during rolling in a cold strip mill, and for indicating any difference in the tension between the two edges of the strip. The device can work in conjunction with auxiliary control equipment in order to maintain automatically any predetermined tension. The value of the instrument in investigations on cold strip-mill rolling operations is discussed.

Electrical Applications in Bethlehem's 72-Inch Strip Mill. F. D. Egan. (Electrical Engineering, 1937, vol. 56, Sept., pp. 1105–1114). A detailed account is presented of the electrical equipment, including motors and generators, at the strip mills of the Bethlehem Steel Company.

Choice of Motor Sizes for a Rolling Mill. J. Knust. (Stahl und Eisen, 1937, vol. 57, Nov. 25, pp. 1330–1331). The author examines the choice of electric motors suitable for the driving of rolling mills. Various types of motors are considered and their relative costs compared on the basis of a given output.

Individual Motor Drives on Wide Strip Mills. F. E. Harrell and W. R. Hough. (Iron and Steel Engineer, 1937, vol. 14, Aug., pp. 23–32). The authors present the results of investigations carried out by means of the oscillograph on run-out tables and coiler drives and on the adjustable-frequency motor-alternator sets in operation in various wide-strip mills.

HEAT TREATMENT

(Continued from pp. 66 A–72 A)

Diffusion in Solid Metals—III. A. I. Krynitsky. (Metals and Alloys, 1937, vol. 8, Sept., p. 261). The author presents as an addendum to the correlated abstract on diffusion in solid metals which appeared in earlier issues of Metals and Alloys, van Liempt's discussion on the formulæ of himself and Dushman and Langmuir. (*See also* Journ. I. and S.I., 1937, No. II., p. 264 A).

Causes of Trouble in Heat Treatment. W. F. Chubb. (Metallurgia, 1937, vol. 16, Oct., pp. 199–200). The author suggests a procedure for remedying difficulties caused by the presence of free cementite in the case of carburised components. The process is based on the spheroidisation of the cementite network; the work is cooled in the box to a temperature below the Ar_1 point and is then placed in a second furnace and held at 650–690° C. for a predetermined time depending on the size of the work, the degree of overcarburising and the results desired. The advantages of this treatment are outlined.

Surface Hardening by the Acetylene-Oxygen Flame. W. Eberle. (Engineering Progress, 1937, vol. 18, Sept., pp. 205–208). The author discusses the general nature of the flame-hardening process, the choice of steel to treat by the process, the hardness and depth of case attainable, various flame-hardening techniques, the advantages of the process, applications of flame-hardening and machines for carrying out the work, particularly repetition work.

Scaling of Chromium Steels. (Metallurgist, 1937, vol. 11, Oct. 29, pp. 70–72). The work of W. Oertel and W. Landt on the scaling properties of steels of various chromium and carbon contents is critically reviewed. (*See also* Journ. I. and S.I., 1937, No. II., p. 187 A).

A Portfolio of Heat Treatment Handling Methods. F. Juraschek. (Iron Age, 1937, vol. 140, Oct. 28, pp. 52–52E). The author discusses the limitations imposed on mechanical handling equipment for use in heat-treatment plant; high temperature and corrosion by products of combustion constitute the main problems encountered. A number of typical handling and conveyor installations in the heat-treatment departments of certain American companies are then described.

Various Types of Heat Treatment for Steel Defined by Temperature–Time Curves. J. Seigle. (Revue de l'Industrie Minérale, Mémoires, 1937, No. 403, Nov. 1, pp. 514–524). The author examines critically the relationship between the types of temperature–time curves obtained and the heat-treatment procedures adopted for steel. Some discussion is included on the theory of

the effect of the cooling velocity during the quenching process. Data are presented in graphical form.

The Modern Heat Treatment of High Speed Steel Tools. J. P. Gill. (Industrial Heating, 1937, vol. 4, Oct., pp. 827–834). The author tabulates the compositions of and recommended heat treatments for ten varieties of high-speed steel with from 14 to 21% of tungsten and including types containing from 4·5 to 12·5% of cobalt and a tungsten-free type containing 8·5% of molybdenum. The equipment and technique for forging, annealing, hardening, rehardening, pack-hardening, cyanide-hardening and nitriding, and tempering are then discussed in detail.

Drill Making at Ford's Village Unit. J. B. Nealey. (Iron Age, 1937, vol. 140, Nov. 4, pp. 46–48). An account is presented of the drill-making unit erected for the Ford Co. at Newbury, Michigan. The plant employed to manufacture the drills from an 18% tungsten, 4% chromium, 1% vanadium high-speed steel is described, and particular attention is paid to the continuous, full-muffle type of gas-fired hardening furnace and to the vertical high-pressure-gas-fired tempering furnace.

Controlled Atmosphere Annealing. E. C. J. Marsh and E. Mills. (Metallurgia, 1937, vol. 17, Nov., pp. 25–27). The authors discuss the general arrangement of a bright-annealing furnace and the difficulties entailed in its operation. The effect of extraneous and inherent contamination of the work by grease and oxide films respectively is dealt with and means for removing such contamination are considered. The control of the protective atmosphere is also discussed.

A Study of Heat Transfer in an Annealing Furnace. E. G. Fiegehen. (Engineer, 1937, vol. 164, Oct. 8, pp. 382–384). The author describes the application of fundamental principles of combustion and heat transfer to the general design of an oil-fired annealing furnace for steel castings. The car-bottom type of furnace is selected for discussion.

Furnace Anneals Large Pulp Digesters. C. Cleveland. (Heat Treating and Forging, 1937, vol. 23, July, pp. 355–356). An account is given of an annealing furnace 80 ft. long, 14 ft. wide and 17 ft. high, constructed by the Chicago Bridge and Iron Co. The furnace is coke-oven-gas fired.

On the Hardening of Steel. E. Scheil. (Metallwirtschaft, 1937, vol. 16, Nov. 19, p. 1211). The author deals briefly with the physical processes occurring during the hardening of steel. Practical considerations are very briefly noted.

WELDING AND CUTTING

(Continued from pp. 73 A–76 A)

Mechanical High-Speed Resistance Welder Control. F. H. Roby. (Electrical Engineering, 1937, vol. 56, Sept., pp. 1145–1148). An account is given of a control mechanism by which operating speeds of over 350 welds per min. may be attained on pneumatically-operated portable welding tools.

Developments in Resistance Welding. L. B. Wilson. (Welding Industry, 1937, vol. 5, Sept., pp. 297–301). The author discusses the spot-welding process and the development of equipment satisfying the requirements of clean high-duty welds. Particular attention is paid to the means of controlling the duration of the welding operation. The projection welding process and the plant employed for it are discussed. Intermittent seam welding, and the welding of stainless steel and of high-speed steel to mild steel are also referred to.

Production of Steel Tubing by Resistance Welding. (Machinery, 1937, vol. 51, Nov. 11, pp. 157–160). The equipment required for and operations involved in the production of tube from coiled strip steel are described in detail. The steel is welded by revolving electrodes and cut to the required length in a continuous process, the steps of which are examined in detail.

The Use of Welding in Chemical Production. C. W. Brett. (Chemistry and Industry, 1937, Oct. 2, pp. 885–886). Among the applications of welding referred to is its use in the repairing of corroded chemical plant, where a butt-welded joint is definitely preferable to the lap joint resulting from riveting. Mobile electric and oxy-acetylene welding units are noted.

Autogeneous Layed-On Welding in Mining. E. Greger. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 137–141). The author describes the application of welding to the recovery of worn mining equipment and tools. Building up of worn components such as pulleys and boring crowns by layer welding and by hard-facing is discussed.

The Flash Butt Welding of Rails. (B.H.P. Review, 1937, vol. 14, Aug., pp. 6–7). In connection with a scheme of rail service improvement in Victoria, Australia, extensive flash butt-welding operations are being carried out on rails. The technique of the operation is described in detail.

CLEANING AND PICKLING OF METALS

(Continued from p. 23 A)

The Electrolytic Cleaning of Strip Steel. M. Stone. (Iron and Steel Engineer, 1937, vol. 14, Oct., pp. 27–31). The author comments briefly on the purpose and methods of cleaning and passes on to a detailed examination of the electrolytic cleaning of steel strip. The use of 1·25–2·5% aqueous solutions of sodium ortho- and meta-silicates is referred to. The construction, operation and running costs of the plant are discussed, the trend of future developments being noted.

Cleaning for Hot-Dip Galvanising and Tinning. W. G. Imhoff. (Iron Age, 1937, vol. 140, Oct. 30, pp. 37–41). The author describes the development of modern cleaning methods for malleable and grey cast iron prior to galvanising or tinning. The importance of adequate cleaning in the production of perfect coatings is stressed. Rotoblast, Wheelabrator, and Tum-blast cleaning equipments are noted and the procedure for coating with tin by hot dipping is outlined.

A.C. Electro-Pickling. A Better Method of Pickling. A. B. Dove. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 563–570). After a brief account of various electrolytic pickling processes the author proceeds to a consideration of the Ferrolite process in which a complex electrolyte containing sulphuric and gluconic acids is used, the descaling process being initiated by the application of a 25-cycle A.C. current at 6–10 V., this latter figure depending upon the ferrous iron concentration of the bath, and the temperature. The results of experimental work on the Ferrolite process are presented. Wire and wire rods of carbon contents between 0·04% and 0·92% variously heat-treated are said to be pickled rapidly, economically and with low iron losses by this method; brittleness and other pickling defects are said to be absent. Tabular and graphical data are presented.

Phosphoric Acid Pickling. (Engineer, 1937, vol. 164, Dec. 10, p. 665). A description is given of the two-stage pickling process utilised by the Whessoe Foundry and Engineering Co., Ltd., in the treatment of mild steel to prevent corrosion. The material is descaled in sulphuric acid, washed and then treated in a phosphoric acid bath, which causes the formation of a thin surface film of an iron phosphate which is electro-chemically inert and promotes the adhesion of the paint which is applied afterwards.

Inhibited Acid Pickling. An Examination of Inhibitor Action. (Wire Industry, 1937, vol. 4, Aug., pp. 439–443). A general discussion is presented on the evaluation of inhibitors for acid pickling solutions. Testing methods and the advantages to be derived from the use of inhibitors are considered.

COATING OF METALS

(Continued from pp. 24 A–30 A)

The Structure and Mechanical Properties of Protective Films. G. F. New. (Journal of the Society of Chemical Industry, 1937, vol. 56, Aug., pp. 261T–265T). The author describes the techniques for preparing isolated films of paints, varnishes and lacquers of various types, and points out the advantages of the mercury-bath method. The measurement of film thickness, the extension of films under steady load, the tensile strength of films, the effects of ageing before testing, the effect of varying the pigment/medium ratio, the influence of varying the heat treatment of the oils used and the behaviour of films under alternating stress are studied, data being presented in graphical form.

The Structure and Electrical Properties of Protective Films. L. Hartshorn, N. J. L. Megson and E. Rushton. (Journal of the Society of Chemical Industry, 1937, vol. 56, Aug., pp. 266T–270T). The authors discuss the significance of dielectric properties as indicative of the structure of the material composing protective films, refer to the mechanism of the action of adsorbed water films on the dielectric constant, and then describe experimental work on the dielectric properties of cellulose acetate films and phenol-formaldehyde resin films under different conditions. From the results obtained conclusions are drawn as to the structure of the films, the effect of adsorbed water and the physico-chemical nature of the materials.

Some Differences Between the Structure of Electrodeposited and Hot-Dipped Metal Coatings. D. J. Macnaughtan. (Symposium on the Mechanism of Solid Film Formation, London, May 3, 1937: Chemistry and Industry, 1937, Oct. 2, pp. 875–883). The author examines the structural differences between electrodeposited and hot-dipped coatings of tin and zinc. The microstructures of the surface and cross-section of the coatings are compared and certain of the factors determining the structures considered. Structure in relation to behaviour during deformation, boundary embrittlement and the behaviour on deformation of coatings of zinc and tin on steel are dealt with.

Nickel-Cobalt Alloy Plating from Low *p*H Acid Sulphate Solutions. C. B. F. Young and C. Egerman. (Electrochemical Society, Oct., 1937, Preprint No. 25). The co-deposition of nickel-cobalt alloy from a strong acid sulphate bath was studied by means of a rotary cathode. The influence of agitation, current density, temperature, *p*H, and of an addition agent was investigated. The first caused the cobalt content of the alloy to increase, the second caused a decrease in deposited cobalt, the third caused an increase in the cobalt concentration of the alloy, as also did the fourth,

while the addition of a brightening agent did not affect the composition of the deposit.

Removing Nickel Coatings from Steel. G. E. Gardam. (Electrodepositors' Technical Society: Metal Industry, 1937, vol. 51, Nov. 12, pp. 485–486). The results obtained with an anodic process for removing nickel deposits from steel are described. The method was successful, and resulted in no severe corrosion of the basis metal. The method may be used to determine the weight of relatively thin deposits of nickel on steel, and, in a slightly modified form, for removing composite nickel-copper coatings from steel.

Measuring Thickness of Nickel Coatings. M. Ballay. (Electrodepositors' Technical Society: Metal Industry, 1937, vol. 51, Oct. 29, pp. 435–438). The author discusses the "drop" test for determining the thickness of nickel deposits as developed by the French Railways. The results of an investigation of possible variables and optimum conditions for carrying out the test are presented and a suitable technique is suggested. The solution used consists of 80 parts of monohydrated nitric acid, 20 parts of sulphuric acid (66° B.) and 40 parts of distilled water. (*See also* p. 24 A).

Microscopic and Chemical Investigations on Clad Materials. C. Schaarwächter. (Zeitschrift für Metallkunde, 1937, vol. 29, Aug., pp. 270–276). The author discusses in detail the metallography of the interface of iron clad with copper, brass and nickel. The determination of the interface diffusion with respect to both uniformity and depth is discussed, and some consideration is given to the mechanical properties and to the drawing qualities of the clad sheet. Analytical methods for determining the nature and quantity of the cladding metal or alloy are described very fully.

A Metallurgical Study of the Factors Affecting the Quality of Galvanising. R. W. Sandelin. (Wire and Wire Products, 1937, vol. 12, Oct., pp. 545–562). The author presents a study of galvanising defects as affected by the nature of the steel base. Particular reference is made to the grey spotting which occurs on sheet and strip. The effects of controlling the conditions during galvanising are described, including the time of immersion, temperature of the zinc bath, rate of withdrawal and position of the strip during withdrawal. Spotting is shown to be due to the formation of an alloy layer without the usual layer of zinc above it; it is confined to certain grades of steel and may be intensified by acid pickling and by manipulation or other conditions during galvanising; alternatively by suitably modifying the conditions of treatment spotting may be diminished. Tabular data are presented.

On the Reactions of Iron with Molten Zinc. E. Scheil and H. Wurst. (Zeitschrift für Metallkunde, 1937, vol. 29, July, pp. 224–229). The authors determined that molten zinc progressively attacks iron in two different ways, the attack in one case involving the presence of the Γ phase and proceeding parabolically in respect

to time, and in the other case not involving the presence in the alloy layer of the phase mentioned and proceeding at a constant rate. In the first case iron diffuses through the alloy layer and reacts at the alloy-layer/zinc interface, and in the second zinc travels by capillarity to that part of the alloy layer in contact with the iron. Regarding the effect of alloy additions to the iron and to the zinc upon the maximum rate of attack, no general conclusions could be reached; a simultaneous addition of silicon to the iron and aluminium to the zinc—additions which by themselves strongly enhance the reaction between iron and zinc—almost completely suppressed the reaction between the two metals.

The Tin-Plate Industry. (Engineer, 1937, vol. 164, Aug. 13, pp. 174–176). The pack rolling and continuous cold-reduction methods for tinplate production are described and compared from both the technical and economic standpoints. Production statistics are examined and reference is made to the new plant of Messrs. Richard Thomas and Co., Ltd., and to other continuous cold-reduction plants in Germany, Russia and Japan. A consideration of general tendencies concludes the article.

Surface Tension and Viscosity Phenomena in Tinplate Manufacture. B. Chalmers. (Transactions of the Faraday Society, 1937, vol. 33, pp. 1167–1176: International Tin Research and Development Council Technical Publications, 1937, Series *A*, No. 64). The author applies the theories of surface tension and viscosity to the following aspects of the hot-dipping process in the manufacture of tinplate: The appearance of normal pores in terms of the stability of the catenoid film; the appearance of potential pores and grease lines in terms of the theory of the stability of one liquid film on another; the rate of draining the liquid tin under gravity in terms of viscosity.

Measurement of the Thickness of Tin Coatings on Steel by a Magnetic and an Electromagnetic Method. B. Chalmers, W. E. Hoare and W. H. Tait. (International Tin Research and Development Council, 1937, Technical Publications, Series *A*, No. 66). The authors describe the principles upon which the magnetic and electromagnetic instruments for determining the thickness of tin coatings on tinplate operate, the methods employed for calibrating them, and their applications.

Sprayed Metal Surfaces for Bearings. H. Shaw. (Association of Metal Sprayers: Metal Industry, 1937, vol. 51, Oct. 29, pp. 427–430). The author describes tests carried out with a "frictiograph" and a "contorograph" upon the wearing and running properties of journals sprayed with steel from a wire-fed pistol. Phenomena associated with the running-in and etching in service of bearings are also commented upon. The advantages of the sprayed coating are reviewed.

Metal Colouring. C. B. F. Young. (American Society for Metals, Oct., 1937, Preprint No. 26). The author describes methods

of colouring various metals and alloys by chemical and electrochemical processes.

Evolution of Enamelling. W. E. Benton. (Institute of Vitreous Enamellers, Oct. 1937: Foundry Trade Journal, 1937, vol. 57, Oct. 14, pp. 307–310). The author surveys the development of the technique of vitreous enamelling from pre-Roman times to the end of the eighteenth century.

Stannic Oxide as Opacifier in Wet Enamels. L. Stuckert. (Institute of Vitreous Enamellers, Oct. 1937: Foundry Trade Journal, 1937, vol. 57, Oct. 14, pp. 310, 306; Nov. 4, pp. 359–364). The author discusses the favourable influence exerted by stannic oxide additions to vitreous enamels upon the impact and thermal resistance, acid resistance and, in conjunction with fluorides, upon opacification. The importance of particle size in this last connection is considered.

The Adhesion of Enamels to Iron. J. White. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1937, vol. 57, Dec. 2, pp. 437–438, 440). After a preliminary discussion on the adhesion phenomena observed between vitreous enamels and metals and on theories concerning the adhesion of enamels to iron, the author examines the rôle of oxygen in the adhesion process, the mechanism of oxygen transfer through fused enamel and the function of cobalt oxide in promoting adhesion. Graphical data are presented.

Enamel Thickness Gauge. S. H. Bastow and R. H. Whillock. (Transactions of the Society of Chemical Industry, 1937, vol. 56, Oct., pp. 403–405). An account is presented of a magnetic device for determining the thickness of vitreous enamelled coatings on steel. The specimen is employed as a magnetic shunt, the disturbing effects of the enamel coating being determined by a torsion method calibrated against sheets provided with a definite thickness of enamel. Reference is made to an electrical instrument operating on alternating current and devised by the General Electric Company.

Large Oven for Baking of Finish on Automobile Frames. (Industrial Heating, 1937, vol. 4, Oct., pp. 890–892, 914). An account is given of a multiple-pass monorail-conveyor oven installed for baking the enamel finish on automobile frames at a Detroit automobile-frame plant by Industrial Sheet Metal Works Inc., Detroit, Michigan. The oven is 29 ft. high, 89 ft. long and 61 ft. wide. Ross direct-fired gas heaters are employed for heating purposes, and the oven is lagged with 4 in. of rockwool. It is capable of handling 125 frames per hour.

Simplified Testing Methods for Paint Films. E. Rossmann. (Angewandte Chemie, 1937, vol. 50, Nov. 6, pp. 854–856). An account is given of the determination of the mechanical and physical properties of protective coatings of a paint-like nature. The use and disadvantages of the Erichsen method are discussed and a standard procedure is outlined. A new type of scratch-testing

machine is briefly described, and methods of determining permeability to water and water vapour are referred to. Graphical and tabular data are presented.

Testing the Weather Resistance of Rustproofing Paints for Structural Steel Work. (Korrosion und Metallschutz, 1937, vol. 13, Sept., pp. 315–316). In a communication from the Czechoslovakian Electro-Technical Society, the methods adopted for testing the rust-proofing paints employed on steel structural work by the Czechoslovakian electricity companies are described. These tests were instituted by the Electro-Technical Society, which set up a committee composed of representatives from all interested parties for the purpose. Atmospheric weathering tests were conducted simultaneously with laboratory tests. The results of prolonged natural weathering tests were found to agree well with results obtained with the " Weatherometer " employed to determine the efficacy of short-time tests.

On the Short-Time Testing of Rustproofing Pigments. H. Wagner. (Korrosion und Metallschutz, 1937, vol. 13, Sept., pp. 297–302). Problems in connection with short-time tests on rust-proofing pigments are discussed in terms of the properties required of such pigments in the protective coat. The difference between the properties of the ground and finish coats is discussed, and it is shown that no pigment of universal applicability exists. The necessity for the ground pigments to exert a passivifying effect and the possibility of electro-chemical processes being of general occurrence in normally built structures are also examined. A short-time weathering test is described which appears to be very satisfactory. Among other testing methods the short-time test suggested by Rossmann is put forward as being likely to yield useful data, while a method of evaluating both ground and finish coatings is described.

The Influence of Alteration in Constituents upon Pigment Problems. H. Wagner. (Angewandte Chemie, 1937, vol. 50, Oct. 23, pp. 824–827). The author compares the protective qualities of paints pigmented with unmixed red lead with those of paints with pigments composed of red lead mixed with about 5% of heavy spar and other substitutes, and with iron oxide pigments. Paints containing neutral and basic lead chromate and zinc chromate are also discussed. Support is given to short-time tests as being of value in enabling improvements to be effected in protective pigments. The mechanical properties of the paint films are also examined.

PROPERTIES AND TESTS

(Continued from pp. 77 A–85 A)

Objections to the Yield Point as a General Basis of Design. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report, 1936, pp. 63–64). The general use of the yield point as a basis for the design of machinery is deprecated, and certain essential aspects of design are discussed in relation to this property. It is noted that in so far as a low yield point may allow of stress adjustment at discontinuities, a high yield point may be definitely disadvantageous under certain conditions.

Piston Rings and Cylinder Liners. G. Williams. (Automobile Engineer, 1937, vol. 27, Aug., pp. 299–302; Sept., pp. 333–336). A description is given of a machine for testing gapped rings in tension; the load-extension diagram obtained is considered from a mathematical standpoint and values indicative of elasticity and toughness are derived from it. Permanent set, ring distortion, ring proportions and the necessity for " balanced " physical properties are also discussed in relation to piston rings. Cylinder liners are discussed from a similar standpoint.

Torsion Testing Machines. (Wire Industry, 1937, vol. 4, Sept., p. 489). The construction and operation of the improved Tarnogrocki torsion testing machine are described. Employed for the testing of wire, this instrument is made in both hand- and motor-driven models of various capacities.

Impact Testing from a Physical Standpoint. R. V. Southwell. (Joint Committee on Materials and their Testing: Manchester Association of Engineers, Oct. 29, 1937, Preprint). After commenting on the physical significance of the impact test, the author describes the Oxford ballistic impact testing machine and compares the results obtained on this and the Izod machine; the specimen used in the Oxford machine and the method of loading are also described. The ultimate value of the impact test is then considered in the light of the studies described, followed by an examination of the significance of the dimensions of the specimen and of the so-called scale effect in relation to the propagation of cracks.

Some Aspects of the Notched-Bar Test. L. W. Schuster. (Joint Committee on Materials and their Testing: Manchester Association of Engineers, Oct. 29, 1937). The author discusses briefly the function of the test and then enumerates variations of the single-blow impact test, and considers such factors as dimensional effect with geometrically similar specimens, dimensional effect with dissimilar specimens, effect of varying the width of the specimen and the transition which is marked by an energy increase from a low to a high value when a steel specimen is heated from a low tem-

perature to room temperature. The mechanism of failure, velocity of test, tensile impact tests, form of notch and the use of the round specimen of standard form are also considered. An account is then presented of the experimental verification on a specially designed machine of the aspects previously discussed; data are presented in graphical form.

The Development and Present Position of Continental Research on the Notched-Bar Impact Test. M. Moser. (Joint Committee on Materials and their Testing: Manchester Association of Engineers, Oct. 29, 1937, Preprint). The author describes briefly the purpose and development of the notched-bar impact test, presents an account of the Charpy impact test, the impact specimens and the Charpy impact testing machine, considers the limitations of the Charpy test-piece for technical purposes and discusses the development and characteristics of modified types, which are compared with the original type. German, Italian and French practice are compared and some comments are made on the proposed international standard specimen. The paper concludes with a note on the progress of the test in Great Britain. Data are presented in tabular and graphical form.

Notched Bar Testing. (Metallurgist, 1937, vol. 11, Oct. 29, p. 65). A résumé is presented of certain aspects of the notched-bar test discussed at the meeting of the Joint Committee on Materials and their Testing held at Manchester on Oct. 29. (*See* preceding abstracts).

Work Sensitivity. S. L. Case. (Metal Progress, 1937, vol. 32, Nov., pp. 669–674). After a preliminary description of the uses and limitations of conventional metallographical and physical methods for determining the quality of steel, the author proceeds to a critical examination of the factors governing the susceptibility of carbon steels containing from 0·20 to 0·61% of carbon to cold-working embrittlement. A standard test for work-brittleness is described, and the determination of this property as a measurement of ageing is considered; it is shown that this method is both selective and sensitive. Tabular and graphical data are presented.

Experiments with Cold-Worked Steel as Reinforcement. R. H. Evans. (Concrete and Constructional Engineering, 1937, vol. 32, Oct., pp. 567–573). The results of experiments demonstrate that for equal stresses in tension reinforcement, the deflexion and strains (in the steel) in concrete beams reinforced with cold-worked or overstrained twisted steel rods are greater than those in beams reinforced with high-tensile or carbon steel rods of the same diameter, the beams being identical except for the type of reinforcement employed. The stresses in the steel are shown to be in accordance with the established fact that such stresses are independent of the modulus of the reinforcement.

The Effects of Torsional Overstrain on the Physical Properties of Some Typical Spring Steels, and its Influence on the Shear Stresses

in Helical Springs. L. E. Adams. (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1937, vol. 26, pp. 1–55). Attention is drawn to the conflict between the high shear stresses given by the theory which includes the Röver effect, and the appreciable life yielded by highly stressed helical springs in service. The influence of "scragging" in this regard is noted. Investigations on torsional overstrain (measured to a scale devised by the author) are described, carried out on heat-treated silicon-manganese, chromium-vanadium and mild steels and 1·0% carbon steels, the analyses, microstructures and details of manufacture of which are indicated. Buckton machines were employed for tensile testing, and a 12,000-lb. in. Avery machine for the torsion tests. Extensometers of the Martens type, for which sensitivity data are presented, were used for strain determinations. An explanation based on lattice deformation is advanced for the different reactions of mild steels and 1·0% carbon steels in the overstrained condition to mild heat treatment, the effects of which were found to vary according to the temperature and duration of soaking. Complete restoration of elasticity is conditioned by the temperature of treatment exceeding a critical value. Consideration of actual shear stress distribution in overstrained specimens provides some explanation of the limited but useful life obtained from highly stressed helical springs in which theoretical stress conditions are largely modified by scragging. Repeated solid loading followed by heat treatment above a critical temperature is shown to lead to agreement between the actual and theoretical distribution of stress. Some suggestions based on this fact are given for improving the performance of springs in service, but the need for investigation of fatigue resistance is noted where cyclic loading occurs. It is shown that the ratio of the torque sustained by the overstrained test-piece with elasticity completely or partly restored at the point where the torque-twist curve ceases to indicate a linear relationship, to the torque applied to the specimen during the overstraining operation, varies linearly with the mean value of the overstrain for the fibres of an over-strained annulus. The application of the phenomenon of lower yield stress in tension to torsional overstrain is also examined. Torsional overstraining with mild heat treatment produced in general an increase in the ultimate tensile strength of the steels, and in every case the proportional limit stress curve in tension was of parabolic form and gave a maximum value for this stress. In torsion, the curves of equivalent shear stress at rupture were also parabolic and indicated a minimum value for the stress; the mean value of overstrain for the fibres of an overstrained annulus at this point was equal to that at the point of maximum proportional limit stress. Proportional limit stresses tended to an upper limiting value. Differences observed in one group of tests between the extension and twists at rupture as determined by direct measurement, and as deduced from rupture curves, are attributed

to elastic afterworking. When elasticity was not completely restored by heat treatment, the modulus of rigidity was found to decrease with increasing overstrain, and two values were found, corresponding to the initial and secondary limits of proportionality indicated on torque-twist curves; the practical value of the second modulus is noted. With elasticity partially restored, the two moduli of rigidity increase with repeated overstrain followed by mild heat treatment. Variations of Young's modulus appear to be independent of overstrain in all cases. Breaks in the elastic lines, consequent upon a second overstraining of the specimen subsequent to a preliminary overstraining of a somewhat higher order followed by mild heat treatment, are attributed to strain-hardening, the effects of which, therefore, are apparently observable within the elastic range. Values for the ratio of proportional limit stresses in torsion and tension are shown to depend on the history of the specimen, and particularly on the degree of overstrain with subsequent mild heat treatment. The observed value of this ratio, and that required by the total strain-energy theory of Beltrami and Haigh, are shown closely to approximate in the case of specimens which have not been overstrained. Data are given for combining stresses in bars of elliptical and rectangular section according to the method of Saint Venant.

" Yielding " Phenomena and Distortion in Iron, Steel, Aluminium Alloy and Other Metals Under Stress. E. W. Fell. (Iron and Steel Institute, Carnegie Scholarship Memoirs, 1937, vol. 26, pp. 123–163). The memoir deals with the distortion associated with sudden yields in aggregates of metallic crystals under stress. Yielding phenomena—and particularly the remarkable yield in soft steel—are attributed to slip along parallel planes extending right through the aggregate. In this way, one layer moves over its neighbour in a manner like that seen when slip takes place in a pack of cards. Such motion is attributed to the presence of a large number of possible crystallographical planes of slip so that the aggregate can shear on a single plane in any direction. Conditions tending to increase the number of these slip planes in an aggregate are an increase in the number of crystals forming the aggregate and in the number of possible slip planes in the crystal. Propagation of slipping along a plane right through an aggregate is thus explained. Yielding phenomena are very closely associated with the " lines of Hartmann." Part I. describes an investigation of the peculiar relationship between the inclination of the surfaces of slip associated with these lines, and the surfaces of maximum shear stress in the aggregate. Part II. describes an investigation of the distortion of the lattice structure of iron on yielding by means of newer X-ray diffraction methods. Ageing and other changes subsequent to straining are investigated also. Part III. describes yielding phenomena in an aluminium alloy which resemble those is soft steel in a general way though differing in detail. The dis-

tribution of permanent strain is examined for duralumin. Part IV. describes these yields in metals and attempts to reproduce them in cases likely to support the theory put forward. They are discussed also with regard to existing theories.

Jovignot's Cupping Test for Sheet Metal. (Iron Age, 1937, vol. 140, Sept. 16, pp. 51–54; Sept. 30, pp. 29–31). **Examination of the Jovignot Method of Cupping by Fluid Pressure.** (Sheet Metal Industries, 1937, vol. 11, Sept., pp. 817–818). English translations have appeared of an article by P. Bastien describing Jovignot's method of carrying out cupping tests. The original article appeared in Revue de Métallurgie, Mémoires, 1937, vol. 34, May, pp. 339–346. (*See* p. 32 A).

The Failure of Girders under Repeated Stresses. F. C. Lea and J. G. Whitman. (Journal of the Institution of Civil Engineers, 1937, Nov., pp. 119–152). The authors describe the apparatus and technique for and the results of investigations on the mechanism of the failure of girders under repeated stresses. A special girder fatigue testing machine was employed, and tensile tests on specimens from joists, bending-fatigue tests on mild-steel girders with rivet holes in the flanges, static tests on a mild-steel joist, fatigue tests on butt-welded mild-steel joists and tests on "Chromador" steel girders were carried out. The direction of future work is indicated, the results of the tests discussed and the meaning of the factor of safety is examined.

The Development of Cracks in the Wheel-Seats of Axles Within the Hubs of Wheels. G. W. C. Hirst. (Journal of the Institution of Engineers, Australia, 1937, vol. 9, June, pp. 215–228). The author discusses the development of fatigue in an axle at the site of tensile stresses due to radial pressure from the hub of the wheel which is attached to the axle by pressing on. The cause of the fatigue cracking is examined from the standpoint of fundamental conceptions of elasticity, and the resulting conclusions are supported by direct photo-elastic investigations.

Investigation of Bending Fatigue and Tension-Compression Fatigue. G. Welter. (Revue Technique Luxembourgeoise, 1937, vol. 29, Sept.–Oct., pp. 101–109). The author compares the tension-compression testing method with that involving the fatigue failure of the test-piece by bending; inherent disadvantages of the latter method are briefly noted. A new type of machine for tension-compression fatigue testing is described in detail together with methods of calibrating it for static and dynamic loading. Results obtained on 0·15% and 0·18% carbon steels are referred to.

An Automatic Electrical Fatigue-Testing Machine. C. F. Wray. (Engineer, 1937, vol. 164, Sept. 3, pp. 251–254). A detailed account of the recently improved design of automatic electrical fatigue-testing machine developed by the Wire Ropes Research Committee of the Safety in Mines Research Board is presented. The machine operates by the passage of an alternating current of

known characteristics through the specimen which is mounted in a powerful magnetic field. The electromechanical theory, design and applications of the machine are considered.

A Study of the Damping Characteristics of an Elastic Vibration. S. Higuchi. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Sept., pp. 236–242). The author presents a mathematical study in which, by introducing the internal resistance of a solid possessing normal solid friction, the solution of the longitudinal oscillation of an elastic rod is obtained. The effects of this resistance upon the decay of elastic vibrations are examined in detail.

Jernkontoret's Standard Hardness Blocks for Rockwell C Testing. A. Hultgren. (Jernkontorets Annaler, 1937, vol. 121, No. 10, pp. 619–632). The Rockwell C test, whilst highly sensitive, is apt to be insufficiently accurate unless the machine is periodically checked against standard specimens of accurately determined hardness. By the choice of suitable steels and suitable heat treatments, blocks accurate to within $\pm$ 0·2 Rockwell C units have been produced covering the hardness values of 65, 60, 55 and 50 Rockwell C respectively. The steels used are high-speed steel and high-carbon high-chromium steel. The heat-treatment technique, which is described, is designed to secure constant dimensional accuracy; this, it is assumed, ensures constancy of hardness. The lapping and calibrating processes are also described.

Hardness Measurements on Structural Constituents. E. M. H. Lips. (Zeitschrift für Metallkunde, 1937, vol. 29, Oct., pp. 339–340). The technique of and apparatus for determining the hardness of micro-constituents in polyphase alloys are discussed, a small instrument consisting of a Vicker's diamond loaded with a 30-g. spring being employed; this is substituted for the objective in the microscope, the specimen being indented by racking up the specimen against the diamond. The objective is next replaced and the indentation measured. Experiments on cast iron are referred to.

Testing the Hardness of Thin Coatings by the Scratch-Hardness Method with the Modified Martens Testing Machine. G. Richter. (Zeitschrift für Metallkunde, 1937, vol. 29, Oct., pp. 355–356). Whilst the Martens scratch-hardness testing machine has proved unsuitable for determining the hardness of electrodeposited surface coatings of 1 μ and upwards in thickness, a modified instrument employing a 120° diamond cone loaded in units of 0·01 g. to give a scratch 3 μ wide (and approximately 0·86 μ deep) has proved very satisfactory. The hardness is defined in terms of the number of unit loadings required to give a scratch 3 μ in width.

Notes on Microstructure and Hardness of Alloys Consisting Essentially of Iron, Chromium and Silicon. A. G. H. Andersen and E. R. Jette. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 853 : Metals Technology, 1937, vol. 4, Oct., No. 7). The authors discuss the metallography and hardness values of alloys of iron with chromium and silicon, the

former ranging from 2·28% to 57·28%, the latter from 0·05% to 1·51%. Ageing, quenching and annealing phenomena are also studied from the standpoint of their influence on hardness.

Concerning Phenomena in Metals at Room Temperature. H. Hanemann. (Metallwirtschaft, 1937, vol. 16, Nov. 19, pp. 1203–1205). The author examines low-temperature ageing phenomena in metals. Diffusion processes occurring in 0·06% carbon steel between room temperature and 100° C. are noted, and certain aspects of the $\alpha \rightleftharpoons \gamma$ transformation in high-carbon steels at low temperatures are referred to. The practical significance of such processes is briefly discussed.

The Wear of Cast Iron. J. G. Pearce. (Institution of Mechanical Engineers, General Discussion on Lubrication and Lubricants, 1937, Oct., Group II., pp. 156–159). After a brief preliminary discussion on wear tests, the author discusses the effect of the composition of grey cast iron on its wearing properties, this being followed by a consideration of the effect of structure. The influence of heat treatment on wear-resisting properties is also dealt with. Reference is made to nitrogen-hardened cast iron and to the use of chromium-plated irons for resisting wear.

Investigations on the Wear of Rail Steel. E. Cotel. (Report on the Work of the Szechenyi Scientific Society, Budapest, 1937, pp. 65–66). The author summarises the results of investigations on the wear of steel rails carried out with specially designed apparatus. He concludes that in unalloyed steels with carbon from 0·4% to 0·9% the wear increases in direct proportion to the decrease in carbon content, and that the carbon content provides an index of wear resistance. The least wear is exhibited in straight carbon steels with an all-pearlite structure. Steels with carbon in the region of 0·4% are recommended. Attention is directed to the deformation of rails in service.

Magnetic Testing. R. L. Sanford. (United States National Bureau of Standards, 1937, Circular No. C 415). Information is presented concerning the magnetic qualities and characteristics of metals, the principles employed in the apparatus used for determining the magnetic constants of metals, and the theory and application of magnetic analysis. Reference is made to the determination of defects in ferromagnetic bodies.

Magnetostriction. W. Alexander and J. Swaffield. (Beama Journal, 1937, vol. 41, Oct., pp. 99–104). The authors discuss the methods of producing and measuring magnetostriction; the phenomenon is discussed in relation to iron, nickel, nickel-iron alloys and cobalt, and some practical applications are considered.

Study of Alloys of High Permeability and High Electric Resistance. K. Mihara. (Japan Nickel Review, 1937, vol. 5, Oct., pp. 504–516). The author presents the results of studies on alloys characterised by high permeability and high electrical resistivity and containing 55–80% of nickel, 1–6% of copper, 1–5% of chromium,

1–5% of manganese and the balance iron. Curves are given showing the effect of heat treatment on the permeability; other tabular and graphical data deal with hysteresis losses and with resistivity.

Use of Nickel in Magnetic Alloys. K. Honda. (Japan Nickel Review, 1937, vol. 5, Oct., pp. 430–439). After discussing the ferromagnetic metals and magnetic phenomena associated with them, the author proceeds to consider magnetostriction in single crystals of iron and nickel, and the iron-nickel and iron-nickel-cobalt systems.

Control of Magnetic Quality by Surface Treatment. T. F. Wall. (Engineer, 1937, vol. 164, Aug. 13, pp. 183–184). The author describes the results of experiments on the permeability and hysteresis characteristics of nickel and Armco-iron wires treated in such a manner that any dissymetry of molecular forces at the surface was largely eliminated; with this dissymetry, any forces considered to lead to corresponding dissymetry in the surface magnetic forces were also eliminated. The wires were coated with copper, aluminium or nickel, the coatings being diffused into the basis metal by subsequent heat treatment, thus producing a non-magnetic skin in intimate contact with the core. High permeability and low hysteresis losses were obtained.

On the Thermal Conductivity of Pure Iron. D. Hattori. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Sept., pp. 190–205). The thermal conductivity of Armco iron at various temperatures between 30° C. and 700° C. was determined by means of a newly-designed apparatus. For the lower temperature limit the most probable value for the thermal conductivity of pure iron was taken as 0·174 cal. per °C. per cm. per sec., the range being between 0·172 and 0·175.

Expansion Properties of Nickel-Iron Alloys. (Nickel Bulletin, 1937, vol. 10, Oct., p. 237). Data are presented in tabular form respecting the coefficients of thermal expansion of iron-nickel alloys containing 36, 42 and 48% of nickel at temperatures between 0° and 300° C., 0° and 350° C., and 0° and 450° C. respectively. Values are given for the materials in the hard and soft states.

The Behaviour of Steels at High Temperatures, Progress Report. O. Leihener and P. Grün. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 354–365). The authors discuss creep and fatigue phenomena in low-carbon and low-alloy steels at temperatures in the neighbourhood of 500° C., and the effect upon these properties of mechanical working, the method of manufacture and grain size. Temper-brittleness is discussed together with resistance to hydrogen embrittlement and decarburisation under pressure. Heat-resisting steels are considered in the concluding pages of the article, the effects of various alloy constituents being noted and the influence of environmental conditions examined. Tabular and graphical data are presented.

Hardness of Steel at High Temperatures. (Metallurgist, 1937, vol. 11, Oct. 29, pp. 67–69). The work of Hruska, Körber, Simonsen and Walzel on the hardness of steel at high temperatures is critically reviewed. The logarithmic relationship between hardness and temperature suggested by Hruska is not supported by the work of Körber and Simonsen, while the occurrence of a second maximum of the dynamic hardness at about 150–250° C. as indicated on curves obtained by Walzel does not appear on the usually accepted curves.

The Diffusion of Hydrogen Through Steel. (Metallurgist, 1937, vol. 11, Oct. 29, pp. 75–77). The results of various investigations on the mechanism of the diffusion through steel of hydrogen produced by chemical or electrochemical means during the pickling process are summarised and discussed. Subsequently a summary and a brief critical review of the work of W. Baukloh and W. Retzlaff on this problem is presented. (*See also* Journ. I. and S.I., 1937, No. II., p. 231 A).

A New Classification of Metallurgical Products. P. Blanchet. (Association Française pour l'Essai des Matériaux, June, 1937: Revue de Métallurgie, Mémoires, 1937, vol. 34, Sept., pp. 513–519). The author presents a new system of classification for metallurgical products of general applicability and said to be free from certain disadvantages attaching to the relatively arbitrary standard classifications employed in France, England, Germany and the United States of America.

Chemically Pure Iron. J. Seigle. (Technique Moderne, 1937, vol. 29, Nos. 15–16, pp. 538–544, 576–580). The author discusses difficulties in connection with the determination of certain of the properties of pure iron as functions of temperature. Crystals and crystal aggregates are discussed in general and with respect to iron, and certain peculiarities in very pure irons and steels such as Armco iron, electrolytic iron and carbonyl iron are examined. Experimental results on high-purity iron are considered together with dilatometric curves on similar material. Certain peculiarities observed in nickel between 100° C. and 500° C. are referred to. The existence of a sharply defined $\alpha \longrightarrow \gamma$ transformation temperature is considered to be difficult of admission.

Determines Cast Iron Properties. J. M. Lessells. (Joint Regional Conference of the New England Foundrymen's Association, the American Foundrymen's Association, and the Massachusetts Institute of Technology: Foundry, 1937, vol. 65, Sept., pp. 36–37, 90). After noting the wide variations in the recorded values of the modulus of elasticity of cast iron, the author suggests the employment of a method involving the plotting of a stress/strain relationship for a series of cycles of loading and unloading. Such a method, it is claimed, gives consistent values and provides also a valuable means of comparing different irons. The transverse test, the ratio of transverse to tensile strength, and notched and

unnotched impact tests with single and repeated blows are also discussed.

Attempts at the Better Utilisation in Constructional Work of the High Qualities Attained in Cast Iron. A. Thum. (Giesserei, 1937, vol. 24, Oct. 22, pp. 533–537). The author considers the applicability of cast iron to constructional work by reason of the ease with which it is produced in any required form and because of its low notch sensitivity. The development of the cast crankshaft and improvements which may be effected in its load-carrying capacity by improved design are dealt with, and some reference is made to the heat treatment of grey iron.

Present Position and Technique of Application of Castings in Wear-Resisting Iron. T. Boissaux. (Revue Technique Luxembourgeoise, 1937, vol. 29, July–Aug., pp. 77–82; Sept.–Oct., pp. 110–116). The author reviews briefly the physical significance of wear, and the use of certain types of iron to overcome difficulties encountered in this connection. A summary of factors of importance in connection with the wear resistance of iron is followed by a more detailed examination of various types of iron which are classified according to structure. Finally the action of various alloying elements is considered

Austenitic Cast Irons in the Generation and Distribution of Power. (Nickel Bulletin, 1937, vol. 10, Nov., pp. 234–236). The uses of the austenitic cast irons, Nicrosilal, Ni-resist and Nomag in boiler-house plant, Diesel-engine construction, and in the generation and distribution of electricity are briefly discussed, reference being made to the particular physical and mechanical properties of each which fit it for special applications of these types.

Internal Stresses and Stability of Cast-Iron Rolls. V. Krasovitsky. (Stal, 1936, No. 10, pp. 49–56). The author discusses the breaking of cast-iron rolls immediately after casting or after short service, and criticises the prevalent theory that such failures are due to internal stresses. Only radial stresses have been experimentally demonstrated, and these occasion longitudinal, but not transverse, fracture or cracking. Moreover, radial stresses are potentially not dangerous, since they are opposite in sign to those caused by the heating of the rolls in service. Failure occurs owing to structural weakness; the dendritic structure is orientated with the axes perpendicular to the roll surface and the strength of the roll under these conditions is low. To remedy difficulties of this type the author suggests the use of a more uniform pig-scrap mixture for the production of the rolls, the use of an iron lower in manganese and phosphorus, longer annealing and the ageing of the rolls for 5–6 months before putting them into service. (In Russian).

Copper in Cast Iron and Malleable Iron. W. B. Sallitt. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Nov. 4, pp. 354–357; Nov. 11, pp. 379–380). The author describes the influence of copper on the structure of cast iron and

compares the corresponding influence of additions of silicon. The mechanism of the influence of copper on the structure is discussed together with its effect on the mechanical properties of the metal. The use of balanced alloy additions is considered. The effect of copper additions on the annealing properties of blackheart and whiteheart malleable castings is dealt with and the influence of that metal on the mechanical properties is studied.

Developments in the Production of Malleable Castings.—X. Alloy Additions. H. H. Shepherd. (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 47–51). After describing the effects of various elements on malleable cast iron the author considers in detail the advantages and disadvantages of copper as an alloying element. The influence of molybdenum, nickel, chromium, chromium and copper, aluminium and titanium is also discussed. The influence of the additions on the physical and mechanical properties is examined. (*See also* Journ. I. and S.I., 1937, No. II., p. 220 A).

New Solutions of Old Problems. (Metallurgia, 1937, vol. 16, Oct., pp. 189–191). An account is given of the heat-resisting and abrasion-resisting alloys manufactured by Follsain Metals, Ltd. Surface treatment of mild and cast steel and of certain iron castings by the diffusion into the surface of these materials of other metals which give rise to the formation of strongly adherent surface layers resistant to heat and to attack by hot combustion gases is also dealt with. Some reference is made to the plant at the Follsain Works.

Chromium-Manganese Steels as Heat-Resisting Steels. J. H. G. Monypenny. (Metallurgia, 1937, vol. 17, Nov., pp. 7–12). Following a preliminary discussion on the composition and requirements of heat-resisting steels, the author considers the chromium-manganese steels containing 18% of chromium and manganese contents from 7·0% to 16% and over. The metallography, the effects of heat treatment, the effects of varying the composition, and the physical properties of the steels are considered; the most suitable alloy of the class is said to be that containing 0·15% of carbon and chromium not above 15·0%. This steel, with the requisite manganese, is entirely austenitic; the ferritic steel is unsuitable for heat-resisting purposes.

Heat-Resisting Steels. Sir Robert Hadfield. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, Publication F 4). The author describes briefly the mechanism of the scaling of steel, outlines the evolution of heat-resisting steels, and describes their resistance to scaling and corrosive gases, their strength and stability at high temperatures, their resistance to wear and impact and their incorporation into equipment designed for high-temperature work. Some discussion is included on the application of the steels to various specific purposes.

Corrosion-Resisting Steel in Civil Engineering. (Nickel Bulletin, 1937, vol. 10, Oct., pp. 201–205). A general account is presented

of the use of 18/8 stainless steel in civil engineering work. Tubular and rod reinforcing members for concrete structural work are cited, and special plates used in the construction of dams, tie bars in masonry work, spindles, rivets and wire ropes are also noted.

Acid-Resisting Plant for Dealing with Highly-Corrosive Pit Water. E. Steele. (National Association of Colliery Managers: Iron and Coal Trades Review, 1937, vol. 135, Oct. 29, pp. 695–696). The author discusses the handling of highly corrosive water from the Spencroft coal seam, the principle corrosive agents in which are ferric and ferrous sulphates. Typical failures are analysed and the measures taken to protect water mains and equipment are discussed. The use of non-metallic pipe is dealt with and the application of Staybrite components to pumping equipment is referred to.

Rustless and Corrosion-Resisting Steels. R. Schäfer. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 337–353). The author discusses the development and mechanical and chemical properties of the high-chromium and austenitic nickel-chromium steels. The effects of heat treatment are considered and some reference is made to the machining properties of the steels. The corrosion resistance of both types of steel is dealt with at some length, and the special applications of each are indicated.

Corrosion-Resisting Steels for Turbine Blades. J. H. G. Monypenny. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 365–375). Exposed to pure chloride-free steam chromium steel containing from 12 to 14% of chromium is suitable for turbine blades operating at temperatures up to 500° C. Under less favourable conditions this steel is satisfactory for low-pressure components. The low-carbon alloys of this group are more satisfactory than the higher-carbon alloys, since they show little tendency to harden either by cold-working or by rapid cooling; in addition they exhibit greater corrosion resistance in the presence of traces of chlorides. Steam contaminated with chlorides exerts powerful corrosive effects in the high pressure, and, to some extent, in the medium-pressure cylinders of turbines. Steels containing 16–20% of chromium and 2·0% of nickel and certain austenitic steels are suitable for use under these conditions and are on the whole more resistant to corrosion than the non-hardening austenitic steels containing 10–12% of chromium. Of the austenitic steels those containing 18–20% of chromium and 8–12% of nickel are highly resistant to chloride-bearing steam; they should be resistant to intercrystalline corrosion.

Columbium in Steels. W. D. Wilkinson. (Metal Progress, 1937, vol. 32, Nov., pp. 661–665). After a brief historical account of the isolation of niobium (columbium) the author refers to the physical and chemical properties of the metal and then considers in detail the use of the metal in 4–6% chromium steels, welding rods containing 24% of chromium and 12% of nickel and the austenitic

chromium-nickel steels. Its effect on the response to heat treatment, corrosion resistance, microstructure and welding properties of the steels is discussed. The method of adding niobium to the steel is briefly described.

On the Metallic Materials Containing Nickel. T. Mishima. (Japan Nickel Review, 1937, vol. 5, Oct., pp. 463–502). A detailed review is given of the uses of nickel in a wide series of alloys for structural, chemical and electrical engineering work. Among the alloys referred to are the austenite cast irons, the 18/8 nickel-chromium stainless steels and certain low-iron nickel-bearing alloys resistant to hot and to cold hydrochloric acid. Tabular and graphical data are provided.

Nickel Alloys for Dairy Equipment. M. Yamaguchi. (Japan Nickel Review, 1937, vol. 5, July, pp. 283–308). An account is given of the physical and chemical properties of nickel and nickel alloys in regard to their employment for dairy equipment. Pure nickel, nickel-chromium-iron alloys and Inconel are considered among others. Graphical and tabular data are presented in connection with the corrosion-resisting powers of the alloys.

Nickel Alloys in Food-Processing Equipment. T. Okamoto. (Japan Nickel Review, 1937, vol. 5, July, pp. 309–341). The author describes the use of nickel alloys (chiefly Monel metal) in food-processing equipment handling fruits, vegetables, meat and fish. Tabular data are presented regarding the corrosion resistance of nickel alloys and other metals under the conditions encountered in the food-processing industries.

Nickel and its Alloys in the Brewing Industry. H. Okuda. (Japan Nickel Review, 1937, vol. 5, July, pp. 342–354). The author describes the uses of pure nickel and nickel alloys in the brewing industry. Nickel-clad steel storage tanks are briefly referred to.

Steel and Iron in Shipbuilding and Marine Engineering. I.—Hull Construction. J. W. Donaldson. (Iron and Steel Industry, 1937, vol. 11, Oct., pp. 3–6). The author discusses the selection of material for ship construction. Ship plates and their mechanical properties are considered with particular reference to "elastic limit steels" and alloy steels. Materials for rivets, forgings and tubes, wrought iron, cast iron and malleable cast iron, and methods of fabrication are also dealt with.

Tests of Steel Columns, Thin Cylindrical Shells, Laced Channels, Angles. W. M. Wilson. (Illinois University, Engineering Experiment Station, 1937, Bulletin No. 292). The results of investigations on the wrinkling stress (ultimate load divided by the area of a transverse section) of thin-walled cylindrical shells fabricated by butt welding indicate *inter alia* that, under suitable conditions, this stress will be approximately equal to the yield point of the material if this value does not exceed 33,000 lb. per sq. in. and if the material is above 0·25 in. in thickness, and that diaphragms do not appear to

increase the wrinkling stress of such shells loaded as columns. Results are also presented regarding the ratios of the yield points obtainable in laced-channel and angle struts to those of the material of which they are made, and in connection with the load-carrying capacity of such struts.

Low Alloy Steel Castings in Logging and Road Construction. A. Finlayson. (Metals and Alloys, 1937, vol. 8, Sept., pp. 239–244). After noting the use of low-alloy structural steels in the form of welded assemblies for the transport industries, the author describes the applications of low-alloy steel castings for similar purposes, the steel employed being a low-carbon copper-silicon steel with a manganese content above that usually found in structural steels (the exact analysis is not given). Known as " Carcometal " this material is manufactured by the Pacific Car and Foundry Co.

Concerning the Properties of the High-Carbon Iron-Manganese-Carbon Alloys, Particularly their Suitability as Hard-Alloy. G. Haensel. (Dissertation, Technische Hochschule zu Breslau, 1937). After a preliminary discussion on the present status of high-speed steels and hard-metals the author passes on to a description of experiments on compact masses prepared by sintering or melting white irons containing 5% of manganese and 4% of carbon in order to determine their value as cutting alloys. Details of heat treatments are given including those of attempts to nitrogen-harden the material in powder form. Reference is also made to attempts to prepare compacts suitable for nitrogen hardening by sintering a mixture of iron powder and 3% of chromium powder. The value of the alloys produced as cutting agents is discussed at some length.

Recent Developments in Low-Tungsten High-Speed Steels. E. Houdremont and H. Schrader. (Stahl und Eisen, 1937, vol. 57, Nov. 25, pp. 1317–1322). It is noted that the tungsten contents customary in high-speed steels may be reduced to 8% without affecting the cutting properties of the tool if the vanadium content is raised. By partially replacing tungsten with molybdenum, a still more superior cutting power is obtained and a tungsten-free steel containing vanadium and molybdenum below the normal limits has been shown to possess valuable cutting properties. All molybdenum-bearing high-speed steels show a decreased output at high cutting speeds when impact stresses occur, but the decrease is less than that found with 14% tungsten 2·5% vanadium steel, which is less tough than the high-tungsten steels. Molybdenum-bearing high-speed steels are prone to surface decarburisation, but whilst the low-tungsten high-speed steels are more sensitive to overheating than normal high-speed steels the temperature at which burning commences is very little lower than that for normal high-speed steels. Prolonged heating has less effect on the cutting properties of low-tungsten or tungsten-free steels than on normal tungsten high-speed steels.

Investigations on Low-Tungsten and Tungsten-Free High-Speed Steels. R. Scherer. (Stahl und Eisen, 1937, vol. 57, Dec. 2, pp. 1355–1359). Cobalt-bearing high-speed steels are not affected by the lowering of the tungsten from 18 to 14%, but with a simultaneous increase in the vanadium content increased output results. Steels with 10–11% of tungsten, 4% of chromium and 1·2% of vanadium are equal in performance to an 18% tungsten steel containing 1·0% of vanadium. A decrease of the tungsten to 8% can be counterbalanced by the addition of 0·8–1·0% of molybdenum. A 6% tungsten 2·5% vanadium steel is said to be almost equivalent to an 18% tungsten 4% chromium 1·0% vanadium steel. Tungsten-molybdenum steels are referred to containing 2–12% of tungsten and 8–4% of molybdenum. Reference is made to the effect of cobalt additions to the tungsten-molybdenum high-speed steels, and the different effect of this addition on the double carbides which occur in these steels as compared with those which occur in normal high-speed steels is noted. Tungsten-free steels containing about 7·0% of molybdenum and 3·5% of vanadium are referred to together with steels containing 3% of molybdenum and 4% of vanadium.

Molybdenum High-Speed Steels. W. F. Chubb. (Machinist, 1937, vol. 81, Oct. 2, p. 469E). After a brief review of the effects of additions of tungsten and molybdenum to steel, the author considers in more detail the influence of molybdenum in high-speed steel both in conjunction with tungsten and as a substitute for tungsten, in comparison with which it is said to be twice as potent in its effects on the steel. A molybdenum high-speed steel cited contains 0·68% of carbon, 0·25% of manganese, 0·25% of silicon, 3·50% of chromium, 9·50% of molybdenum, and 1·25% of vanadium. The mechanical properties of the steels are discussed.

Molybdenum in Tool Steels. W. F. Chubb. (Metallurgia, 1937, vol. 17, Nov., pp. 17–18). After discussing the effect of molybdenum additions to the iron-carbon alloys, the author deals with the use of molybdenum in tool steels of different types such as die steels containing 0·5–0·7% of carbon, 0·5–1·0% of chromium and 0·15–0·35% of molybdenum. A composition recommended for dies for hot-working contains the same carbon content with 0·75–1·0% of chromium and 0·6–0·9% of molybdenum. For cold-trimming dies and punches a suitable steel contains 0·8–0·9% of carbon, 0·5–0·7% of chromium and 0·15–0·25% of molybdenum; dies of this steel may be used for forging stainless steel and monel metal as it possesses high resistance to abrasion. Another die steel contains 0·4–0·5% of carbon, 1·4–1·8% of nickel, 8·0–9·0% of chromium, and 4·0–4·25% of molybdenum. Molybdenum high-speed steels are also dealt with and one containing 0·65–0·75% of carbon, 3·25–3·75% of chromium, 9·25–9·75% of molybdenum and 1·15–1·35% of vanadium is cited. Heat treatments and mechanical properties are noted.

Carbon-Free Alloys Hard as Tool Steel. W. P. Sykes. (Campbell Memorial Lecture: Metal Progress, 1937, vol. 32, Nov., pp. 649-

654). The author describes the metallography of and hardening phenomena observed in a precipitation-hardening alloy containing 30% of cobalt, 20% of tungsten and 50% of iron. The alloy attains a Rockwell C hardness of 67 by suitable heat treatment.

Progress Report 4 on the Investigation of Detachable Rock-Drill Bits. M. Mosier. (United States Bureau of Mines, July 1937, Information Circular, No. 6951). This report presents comparative statistics on and costs of drilling at eight metal mines in the United States of America, together with a comparison of the use of detachable bits at small mines and large mines, a discussion on the life of drill rods, and general conclusions derived from an analysis of drilling practice at all the mines investigated. (*See also* Journ. I. and S.I., 1937, No. II., p. 157 A).

The Selection of Steel for Automobile Gears. F. W. Rowe. (Nickel Bulletin, 1937, vol. 10, Nov., pp. 229–233). The author describes the physical and mechanical requirements of steels for automobile construction, and then passes on to a more detailed consideration of nickel-chromium-molybdenum steels containing from 3 to 4·5% of nickel, from 0·6 to 1·25% of chromium and small quantities of molybdenum. The applications and advantages of these steels are discussed. Three per cent. nickel, nickel-molybdenum and air-hardening nickel-chromium-molybdenum steels are also dealt with.

Tests of Strength Properties of Chilled Car Wheels. F. E. Richart, R. L. Brown and P. G. Jones. (Illinois University, Engineering Experiment Station, 1937, Bulletin No. 294). Results are presented of tests carried out on cast-iron wheels with chilled treads to determine the following properties: The strains developed at various points in the wheel while it was being mounted or pressed on to a steel axle; the increased strains resulting from the application of static loads to the journals after the wheels had been mounted and were resting on 130-lb. standard rails, the applied loads being as much as four times the permissible wheel load; the increased strains and axle deflections resulting from the simultaneous application of the static loads on the journals as before together with inward horizontal flange thrusts at the point of contact of wheel and rail; the resistance of the wheel rim to loads applied near the edge of the rim. Data are presented in tabular and graphical form.

Third Progress Report of the Joint Investigation of Fissures in Railroad Rails. H. F. Moore. (American Railway Engineering Association, 1937, Bulletin No. 395: Illinois University, Engineering Experiment Station, 1937, Reprint No. 11. (*See* Journ. I. and S.I., 1937, No. II., p. 276 A).

Service-Test Results of Titanium Treated and Silicon Treated Steel Rails. G. W. Quick. (Journal of Research of the National Bureau of Standards, 1937, vol. 19, Nov., pp. 531–534). The service results obtained by the Illinois Central System from titanium-

treated steel rails and silicon-treated steel rails indicate that for rails laid in heavy-traffic territory a slightly larger percentage of the former remain in service after 15 years' use.

Laboratory Tests and Experience of Rails Consisting of One Metal, Compound Rails and Heat-Treated Rails. M. Roš and A. Eichinger. (Berichte der III. Internationalen Schienentagung, Budapest, Sept. 8–12, 1935). This report, which is the completion of an earlier one presented at the Second International Conference on Rails held at Zurich in June, 1932, deals with the testing methods used and the results obtained in the examination of rails in the Federal Materials Testing Station, Zurich, and with the experience gained with experimental rails consisting of one metal, compound rails and heat-treated rails laid in the track of the Gotthard line of the Swiss Federal Railways. From the materials point of view, the problems of the resistance to wear, fatigue and fracture in service are of primary importance.

Silicon Steel for Tyres. P. Yalovoi and P. Botuch. (Stal, 1936, No. 10, pp. 85–91). Experiments were carried out on a steel suggested by Norikov containing 0·65–0·8% of carbon, 0·8–1·0% of manganese and 0·6–0·8% of silicon. The steel is readily melted, but of the tyres manufactured from it 35% failed because of their brittle nature in mechanical tests. Some, however, exhibited considerable toughness, and all possessed high hardness and probably high resistance to wear. Investigations are to be continued. (In Russian).

Flakes in Tyre Steel. K. Sinitsyn. (Stal, 1936, No. 10, pp. 82–84). Tyre billets returned to the reheating furnace immediately after forging exhibit better mechanical properties than those cooled in air after forging. Flaking is prevented by careful control of the steel in the open-hearth furnace during production and of the casting process. During the manufacture of the steel, gases are removed by a strong boiling of the charge, and the teeming is conducted slowly and at not too high a temperature into a thoroughly dry ladle. (In Russian).

Using High-Strength Low-Alloy Steel. H. L. Miller and T. R. Lichtenwalter. (Steel, 1937, vol. 101, Oct. 18, pp. 62–63). The authors describe the welding and fabricating techniques suitable for a steel containing 0·50–1·50% of copper, 0·50–1·00% of nickel and a minimum of 0·10% of molybdenum. This steel, known as Republic Double Strength, is described as a high yield-strength low-alloy steel; it is employed for rail-vehicle structural work and is marketed in two grades containing carbon up to 0·12% or from 0·20 to 0·30%.

Seamless Tubes Made from High-Arsenic Steel. II. D. Ludogovsky. (Stal, 1936, No. 10, pp. 57–68). A continuation of a previous article (*see* p. 15 A). The author discusses the distribution of arsenic in the steel ingots, the surface cracking of ingots of steel high in arsenic, and the preparation of such ingots for rolling. (In Russian).

Macrostructure and Mechanical Properties. (Metallurgist, 1937, vol. 11, Oct. 29, pp. 74–75). A summary and brief critical review is presented on the work of K. Kornfeld on the influence of the cast structure on the mechanical properties of forged steel. The original paper appeared in Stahl und Eisen, 1937, vol. 57, Aug. 5, pp. 870–873. (*See* Journ. I. and S.I., 1937, No. II., p. 245 A).

The Metallurgical Examination of Colliery Haulage Drawgear. J. H. Andrew, R. Jeffrey and W. A. Johnson. (Safety in Mines Research Board, 1937, Paper No. 100). After a preliminary discussion on the materials used for the manufacture of colliery haulage gear, and the mechanical properties of wrought iron and mild steel, the authors proceed to an analysis of the results of a series of inspections of haulage gear. Faults in fabrication and those developing in service are considered, and alternative materials are discussed, particular attention being paid to the merits of a 1·5% manganese mild steel containing 0·15% of carbon. Heat treatment and the embrittlement of the materials are considered.

Quality of Boiler and Firebox Steel. I. Brajnin and S. Iofin. (Stal, 1936, No. 11, pp. 81–94). The authors describe the production of boiler and firebox steel at the Stalin Metallurgical Works, and discuss possible modifications in the conditions of acceptance of these steels. (In Russian).

British Standard Specification for Girder Bridges. (British Standards Institution, No. 153—Parts 3, 4 & 5—1937).

British Standard Specification for the Use of Structural Steel in Building. (British Standards Institution, No. 449–1937).

British Standard Specification for Steel Bearing Plates for Flat Bottom Railway Rails. (British Standards Institution, No. 751–1937).

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 86 A–92 A)

The Use of Polarised Light in the Microscopical Examination of Iron and Steel. J. H. G. Monypenny. (Metallurgist, 1937, vol. 11, June 25, pp. 46–48; Aug. 27, pp. 50–51). The author describes investigations on the structure of iron and steel and on non-metallic inclusions in these materials, by microscopic methods employing polarised light as a source of illumination.

Grinding Micrographic Specimens on a Lead Disc with Bonded Abrasive. K. Amberg. (Jernkontorets Annaler, 1937, vol. 121, No. 9, pp. 603–614). A description is given of a method for grinding micrographic specimens on a lead disc covered with a layer of varnish in which the abrasive is dispersed. When the abrasive has become pressed into the varnish the surface may be renewed by moistening with benzene. Tungsten carbide powder proved satisfactory for very fine grinding, and the method is applicable to difficult specimens such as those required for the investigation of slag inclusions. The specimen can be ground very flat and finer abrasives may be used than in other methods. The method is, moreover, cheaper than that involving the use of emery paper.

Foundry Products Through the Microscope. E. B. Ellis. (Engineering Inspection, 1937, vol. 3, Oct.–Nov., pp. 17–26). After a discussion on the elementary principles of metallographic microscopy, the author examines in some detail typical microstructures found in various types of white and grey cast iron. Some mention is made of austenitic cast irons.

Electron Diffraction. C. S. Barrett. (Metal Progress, 1937, vol. 32, Nov., pp. 655–660). The author describes the theory of electron diffraction, the technique of applying it to metallographic study and the apparatus required for such applications. A more detailed discussion is then presented on the investigation of thin metallic films by electron diffraction methods, and on the use of such methods in studying problems in connection with adsorbed gases on metals and with the so-called Beilby layer.

The Structures of Meteoric Irons. G. Derge and A. R. Kommel. (American Journal of Science, 1937, vol. 34, Sept., pp. 203–214). The authors report on the crystalline structures of two meteorites (the Cañon Diablo and Amalia Farms falls) as determined by X-rays. The metallographic features of the Cañon Diablo sample are discussed, and a Widmanstätten structure similar to that found in meteorites and developed in a 27% nickel iron is referred to. It is concluded that the structures found in metallic meteorites are the result of slow cooling from high temperatures.

The Relationship Between the Microstructure and the Adherence of Scale Deposit. R. Griffiths. (Iron and Steel Institute, Carnegie

Scholarship Memoirs, 1937, vol. 26, pp. 165–174). The author has used a technique of sectioning specimens of steel coated with scale which permits of an enlarged view of the details to be observed. It is shown in the memoir that the composition and structure of the inner layer of the scale, consisting of the ferrous phase, controls to a large extent the adherence of the scale to the steel. The outer layers of so-called magnetite and ferric oxide in turn affect the composition of the inner ferrous layer, and the author shows that in their absence a completely self-descaling type of scale is obtained. The liberation of gases from the steel during scaling causes the formation of a porous layer in the scale, and affects the reaction between the steel and oxygen, which is the ultimate factor controlling the adherence of the scale to the steel.

Recommended Practice for the McQuaid-Ehn Grain-Size Test. I. Fetschenko-Tschopiwski and A. Stanislawski. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 287–292). Two steels containing 0·33 and 0·35% of carbon respectively prepared by different melting practices were case-hardened in various carburising compounds under different experimental conditions; their structure and the depth of penetration of the case were then investigated. A modification of the McQuaid-Ehn test is suggested, the recommended carburising period being 4 hr. and the temperature 900° C.

The JKM Grain Classification. T. Berglund, A. Hultgren and G. Phragmén. (Jernkontorets Annaler, 1937, vol. 121, No. 9, pp. 579–602). Various methods suggested and used for estimating the grain size of microstructures are discussed. A new standard grain-size series described as the JKM grain classification has been defined on the basis of grain-section area, the members of the series forming a geometrical series with a ratio of 2. Owing to the large range of sizes usually present in a structure, a classification based on an arithmetical series would be impractical. Distribution curves for various structures have been drawn up according to the JKM classification, the ordinates representing the total area occupied by all grains belonging to each class; such curves usually show a distinct maximum at a certain grain size which is termed the "leading grain size"; the value of this conception is compared with that of the "average grain size" as a characteristic of the structure. The JKM grain-size chart has been established on the basis of an actual structure and consists of a series of standard structures, each member of the series having a leading grain size conforming to one of the JKM grain classes at a magnification of one hundred diameters. This chart is used for estimating by comparison the leading grain size of any structure having an ordinary grain-size distribution. The leading grain size of a structure photographed at a magnification f is calculated from the number n of the nearest standard structure conforming to it as follows:

$$x = n + 2\,\frac{\log 100 - \log f}{\log 2}.$$

A diagram for the graphical determination of x from n and f is given. For routine estimation the comparison may be made from a screen image the magnification of which is adjusted to match a suitable standard structure, when the leading grain size may be obtained from the equation given above. Alternatively the image may be adjusted to a magnification of one hundred diameters and the leading grain size established by direct comparison; this method is not suitable, however, for very fine or very coarse structures.

Welded Joints. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report, 1936, pp. 76–81). The results of a series of experiments are discussed which were undertaken to determine to what extent the variability in grain size of top-run metal is governed by a change in the welding current with plates initially at the same temperature and by a change in the cooling rate of metal deposited by a standard method, to determine the effects in this connection of particular electrodes, and to determine the variation in the grain size of lower-run metal initially deposited under different conditions when it is refined by a standard procedure for depositing the upper run of metal. Tabular data are presented.

X-Ray Study of Effects of Adding Carbon, Nickel or Manganese to Some Ternary Iron-Chromium-Silicon Alloys. E. R. Jette and A. G. H. Andersen. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication, No. 852 : Metals Technology, 1937, vol. 4, No. 7, Oct.). The solubility of carbon in the α phase of the iron-chromium-silicon system is low, and higher carbon contents diminish the lattice parameter of this phase. Nickel up to 2·0% and manganese up to 4·6% affected the α and Σ phases of the parent ternary system to a negligible degree. None of the added elements appeared to give rise to the γ phase within the concentrations investigated. Detailed results are presented in tabular form.

On the Constitutional Diagrams of Alloys with Nickel as Their Chief Constituent. H. Nishimura. (Japan Nickel Review, 1937, vol. 5, Oct., pp. 440–462). The author presents a comprehensive discussion on the binary and ternary systems consisting mainly of nickel, and of technical importance in connection with electrical and chemical engineering. Among the alloys dealt with are those of nickel and iron. The lattices and microstructures of the alloys are considered.

Iron-Manganese-Silicon and Iron-Manganese-Sulphur. (Metallurgist, 1937, vol. 11, Oct. 29, pp. 77–80). The investigations of Vogel and Bedarff on the iron-manganese-silicon system and of Vogel and Hotop on the iron/iron-sulphide/manganese-sulphide/manganese system are summarised and critically reviewed. (*See also* Journ. I. and S.I., 1937, No. II., pp. 161 A, 204 A).

CORROSION OF IRON AND STEEL

(Continued from pp. 93 A–94 A)

The Application of Potentiometric Methods for Estimating the Corrodibility of Ferrous Alloys. L. Guitton and A. Portevin. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Oct., pp. 564–574). After a preliminary discussion on the electrolytic phenomena associated with the corrosion of metals and alloys by acids, the authors describe the experimental technique developed to estimate corrodibility by measurement of the potential-time curves relative to specimens immersed in hydrochloric acid solutions of densities 1·1 and 1·18 and in sulphuric acid of density 1·4. A series of normal corrosion-resisting steels and another of special corrosion-resisting steels were investigated. Data are presented in tabular and graphical form. It is concluded that, for any given conditions, the corrosion of ferrous alloys in mineral acids is a regular function of their potentials.

Laws and Theories of Dry Corrosion. G. Valensi. (Métaux et Corrosion, 1937, vol. 12, Sept., pp. 161–173; Oct., pp. 195–198). The author discusses the fundamental principles and theories relating to the corrosion phenomena resulting from the exposure of metals and alloys to gases at high temperatures. Thermodynamic considerations are examined and the theory of Nernst is treated at some length. Concentration limits at the points of contact of phases, the laws of diffusion, the influence of gas pressure, and the oxidation of divalent metals are also dealt with. Various types of possible diffusion mechanisms are discussed in conclusion.

An Investigation of Differential Aeration as a Factor in the Localisation of Corrosion. G. D. Bengough and F. Wormwell. (Journal of the Society of Chemical Industry, 1937, vol. 56, Oct., pp. 349T–363T). Experiments on channel iron and composite specimens made up to resemble it in form, show that differential aeration due to different depths of immersion or to geometrical peculiarities of the specimen has no appreciable effect on the distribution of corrosion in 0·5*N* sodium chloride or in many types of industrial water. The physical natures of the surfaces of the specimens affect corrosion and the characteristics of the current between surfaces in electrical connection and different methods of surface preparation have more effect on corrosion distribution than differences of oxygen distribution.

The Lowering of Endurance Strength by Corrosion and the Method of Decreasing Corrosion Effects. O. Föppl. (Werkzeugmaschine, 1937, vol. 41, Oct. (middle), No. 19). In the introductory section the author briefly indicates the effects of corrosion

upon the strength of metals and points out that until the reduction in section caused by such corrosion is considerable no appreciable influence is exerted on the durability. It is noted that in certain circumstances advanced corrosion may have a favourable effect on the endurance strength. The very marked effects of corrosion coupled with simultaneous alternating stressing are then discussed. The development of the study of corrosion-fatigue arising out of the work of Haigh on wire-rope corrosion is then considered, and the corrosive effects of sea-water on materials subjected to alternating stress are compared with those noted in the absence of stresses of this type. The corrosion-fatigue resistance of certain alloy steels is commented upon; under alternating bending stress and when exposed at the same time to the action of tap water, the fatigue strength of *V2AN* steel is reduced by about 25%, and the decrease in endurance strength of electric chromium-nickel-tungsten steel by corrosion is particularly marked, although in air a very high endurance is obtained. The marked contrast between the relative significance of the number of times the stress is applied, or the time for which it is applied, in the case of specimens being tested by alternating stressing in air and in corrosive media is emphasised. The importance of the chemical analysis of the corrosive medium is also referred to; reports of corrosion-fatigue investigations carried out with tap water should include analyses of the water used. The author next proceeds to a consideration of the mechanism of failure by corrosion-fatigue; an experiment to demonstrate the presence of fatigue cracks in a specimen exposed to conditions conducive to corrosion-fatigue but not stressed to the point of failure is cited; the specimen is initially stressed under the requisite conditions and is afterwards broken by the application of a static tensile stress, when the presence of numerous cracks with corroded surfaces becomes evident. In the second section of his article the author discusses the effect of friction as a cause of decrease in the endurance limit of steel; the mechanism of the action is examined and it is noted that a lowering of the endurance limit of a steel rod by as much as 30% can occur as the result of friction caused by a steel ring in which the rod rotates. Essentially the reduced values obtained are the outcome of oxidation, hence methods which will decrease the effects of corrosion in parts subjected to corrosion-fatigue may also decrease the effects of friction in frictional corrosion. The author considers that no valuable results are likely to follow the use of paints as media to enhance resistance to corrosion-fatigue, unless special paints are chosen. Electrolytic protection by the intentional formation of an iron-zinc couple is examined; such a method is said to increase the endurance strength under corrosive conditions by as much as five times. The special effects of a nitrided surface are discussed; such a surface increases the strength of components not only under conditions of alternating stress with exposure to water but also of frictional corrosion. Finally the

decreasing of the effects of corrosion by the application of surface compression is discussed at some length.

Corrosion-Fatigue Strength. A. Thum and O. Ochs. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 380–383). The authors discuss in detail the effects of alternating stress with simultaneous corrosion; the behaviour of corrosion-resisting and structural steels is referred to. Protection against corrosion by surface treatment and by the application of protective coatings of various types is next considered, the addition of inhibitors to corrosive fluid media being noted as a further protective device. In the concluding part of the article the use of induced internal stresses as a protective measure against corrosion is dealt with, the widely different effects of tensile and compressive stresses upon the corrosion-fatigue strength being discussed.

Failure of Crosshead due to Corrosion Fatigue. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report, 1936, pp. 45–46). Failure of a pump suspension rod and crosshead is attributed to corrosion-fatigue arising at an oil hole in the crosshead boss. Pitting observed on the inner surface of the hole is considered to be due to the ingress of moisture and to have initiated the cracking which resulted in ultimate failure.

The Combined Effect of Corrosion and Stress Concentration at Holes and Fillets in Steel Specimens Subjected to Reversed Torsional Stresses. T. J. Dolan. (Illinois University, Engineering Experiment Station, 1936, Bulletin No. 293). The results are reported of an investigation the main object of which was to determine whether the damaging effect of the corrosive action of water flowing on fatigue specimens made of four different types of steel and which were drilled or provided with fillets was cumulative with the damaging effect of the stress concentration caused by such holes or fillets, the specimens being subjected to completely reversed cycles of torsional stress. Of the steels tested under these conditions, all yielded torsional fatigue strengths below those obtained on the same steels tested in air. The added effect of corrosion, however, in relation to the effect of stress concentration caused by the holes and fillets varied with the type of steel, being greatest for a heat-treated nickel-chromium steel and negligible in the case of a low-carbon steel. Subsidiary tests indicated that the effective torsional fatigue stress concentrations resulting from holes and fillets were considerably below the theoretical values. Data are presented in tabular and graphical form.

Influence of Heat Treatment of 18/8 Steel on its Resistance to Pitting. S. Brennert. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 379–380). The resistance to pitting of an 18/8 steel tempered at various temperatures was investigated. Tempering between 500° C. and 900° C. produced a significant reduction in resistance to pitting; a relationship was determined between the tendency to pitting and to intercrystalline corrosion. As a measure

of resistance to pitting, the highest potential at which the material could be anodically polarised without the occurrence of corrosion was determined.

Running-In. A. H. Stuart. (Automobile Engineer, 1937, vol. 27, Sept., p. 318). The author discusses the corrosion of cylinder bores and the effect of the surface condition of the metal and of graphite upon the corrosion. The results of electron diffraction investigations are commented upon, and the behaviour of cast iron as piston rings and the important rôle played by graphite in this connection are discussed.

The Corrosion of Tin in Nearly Neutral Solutions. T. P. Hoar. (Transactions of the Faraday Society, 1937, vol. 33, pp. 1152–1167 : Technical Publications of the International Tin Research and Development Council, 1937, Series *A*, No. 63). The attack of tin by solutions of the alkali metal salts, of certain anions and of the chlorides of a few cations was studied by electrochemical methods. The influence of the surface condition of the specimen and of the chloride-ion concentration on black-spot formation was investigated, and an explanation advanced for the mechanism of attack.

Corrosion of Iron and Steel in Mining, Particularly in Colliery Winding and Haulage Ropes. E. H. Schulz. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 146–152). The author discusses factors affecting the rusting of steel and refers to the increased corrosion resistance of copper-bearing steels and to the favourable effect of higher phosphorus contents in such steels. The rusting of mild steel and of wrought iron are compared and the mechanism of corrosion is discussed. The influence of the type of corroding medium is also examined and the prevention of corrosion in wire ropes by coating with zinc is considered at length.

The Problem of Corrosion in French Refineries. J. Moinard, P. Moyne and J. Nocturne. (Métaux et Corrosion, 1937, vol. 12, Aug., pp. 145–150; Sept., pp. 174–179). The authors describe the corrosion phenomena observed in the petrol refining plant at the Raffinerie de Port-Jérôme de la Standard Française de Pétroles, and the means taken to overcome the difficulties to which they gave rise. The account is preceded by a theoretical discussion on corrosion phenomena in general. Particular reference is made to the various corrosive agents present in the crude and partly refined oils, and to means of neutralising or removing them.

Interesting Examples of Corrosion of Feed Pipes. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report, 1936, pp. 29–30). Corrosion of cast-iron pipes was shown to be due to excessive oxygen concentration in the feed water which passed through them; a faulty pump raised the oxygen content of the water from 1 c.c. to 2·7 c.c. per litre before it passed through the pipes. Pitting in mild-steel tubes subjected to the action of

a clean non-scaling water containing 1·61 c.c. of oxygen per litre was shown to be due to the action of the excessive gas content; additions of lime to the water or the provision of a de-aerator are suggested as preventatives.

Corrosion Problems in Steam Turbine Construction with Special Consideration of Rustless and Corrosion-Resistant Steels. F. Lüben. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 383–386). The author discusses the corrosion phenomena observed in steam turbines and the limitations imposed by the operating conditions of such equipment upon the materials used in its construction. The applications of 13% chromium steels and of 18/8 austenitic steels with additions of titanium, molybdenum and tungsten are discussed and compared. It is pointed out that in most components of a turbine the nickel-free chromium-bearing steels fulfil most requirements.

Hardened Blade Edges as Protection Against Erosion of Turbine Blades. H. Zschokke. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 386–392). Whilst the application of corrosion-resisting steels has enabled many difficulties in connection with corrosion in turbines to be overcome, problems connected with the erosion of turbine blades have not been so successfully solved. Surface treatments and the application of protective coatings have not yielded entirely satisfactory results. Erosion by water is influenced for any given alloy steel by the hardness of that steel, the erosion decreasing with increasing hardness. Reference is made to a German patent, No. 383,250, regarding a cheap and efficacious method of hardening the edge of rustless-steel blades. Experimental results are presented showing that after 23,600 hr. running the erosion of the hardened blades was a twelfth of that observed with fourteen other steels tested simultaneously.

Corrosion Problems in Connection with Water-Supply Equipment. J. Friedli. (Monatsbulletin des Schweizerischen Vereins von Gas- und Wasserfachmännern, 1937, Nos. 1 and 2). The author discusses the conception and origin of processes of corrosion. Electrochemical corrosion is considered at length, the various factors giving rise to it being dealt with individually. Cast iron and austenitic nickel-chromium steel are among the alloys discussed. Internal corrosion of water pipes and hot-water equipment is then examined, cast-iron, mild-steel and galvanised steel pipes being investigated. The influence of the nature of the zinc coating on galvanised components is emphasised. The concluding part of the paper deals with the corrosion phenomena observed on the exterior of water pipes.

BOOK NOTICES

(Continued from p. 98 A–100 A)

"*Bericht über den Leobener Bergmannstag* 1937." (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30). Vienna, 1937: Verlag von Julius Springer.

This issue of Berg- und hüttenmännisches Jahrbuch is devoted to an account of the Leoben Miners Congress, which was held in 1937. The papers presented at the Congress number fifty-seven, and these, which are reproduced, deal with a variety of subjects of interest to those in the mining industry; several are of metallurgical interest and abstracts of these appear elsewhere in this Journal.

BITTER, F. "*Introduction to Ferromagnetism.*" First Edition. 8vo. pp. xi + 314. Illustrated. London, 1937: McGraw-Hill Publishing Co., Ltd. (Price 24*s.*)

This contribution to the "International Series in Physics" describes and correlates the outstanding properties of ferromagnetic substances and attempts a survey of those aspects of ferromagnetism which give promise of being of wider interest in the future. Chapters I. and II. give a brief introduction to magnetic phenomena and an historical survey. The metallurgical aspects of ferromagnetism are described in Chapter III., and, following a short survey of our concepts of crystals and crystal lattices, recent work is discussed on the use of metallic powders and suspensions in exploring magnetic structures. The technique, as evolved by the author, of using metallic powders in suspension to reveal magnetic patterns on iron, cobalt and nickel is very novel, and is likely to prove of extended value. It is thus possible to determine by this method, the grain orientation in certain steels or the presence of ferrite in an austenite phase. Chapter IV., contributed by Dr. T. D. Yensen of the Westinghouse Research Laboratories, deals comprehensively with the preparation of magnetic materials for research work. Experimental difficulty in preparing high-purity metals is well recognised, and much patient investigation has been carried out in attempting the removal of residual solid and gaseous impurities from the ferromagnetic metals. Development of these high-purity metals, together with the study of the metallographical characteristics of ferromagnetic alloys, has provided us with materials possessing more useful magnetic properties. In this connection the development of low-hysteresis-loss alloys, high-permeability nickel alloys and modern permanent magnet materials are of great economic importance. Subsequent chapters are perhaps of greater concern to the physicist, but are of general interest to the metallurgist, and deal with internal fields, magnetisation, mechanical deformation, electrical phenomena, absorption and evolution of thermal energy, together with an appendix by Zwicky on "Co-operative Phenomena." Mathematical sections have been prefaced by simple illustrations so that the lay reader can gather a general understanding of the arguments.

The treatise will be of undoubted value to all who are interested in ferromagnetism, and forms a very notable contribution to our

literature on this borderline subject. Metallurgists and physicists alike will endorse the author's desire that the application of quantitative reasoning in metallurgy and the presentation of metallurgical problems to physicists should receive every encouragement and should lead us to many new and fascinating discoveries. The printing and arrangement of the text conform to the usual excellent standard of the International Series, numerous references are given and the book is suitably indexed.

I. G. SLATER.

International Association for Testing Materials. "*London Congress April* 19–24, 1937". 4to pp. lxxv + 661 illustrated. London 1938: The Association (Price 30*s*.)

This volume contains the comprehensive series of papers, and the discussions thereon, submitted to the London Congress of the International Association for Testing Materials. The papers, which number 211, cover the following subjects: Behaviour of metals (mechanical and chemical) as dependent upon temperature, particularly in regard to high temperature; progress of metallography; light metals and their alloys; workability and wear; concrete and reinforced concrete; natural stone; ceramic materials; textiles; wood cellulose; timber preservation; ageing of organic materials; colours and varnishes; relation between the results of laboratory tests and behaviour in use and service; the bearing of recent advances in physics and chemistry on the knowledge of materials; the properties of materials for the thermal and acoustic insulation of buildings.

The volume also contains an account of the various technical and social functions which took place during the period of the Congress, together with a list of delegates from 33 countries who participated in the proceedings.

MALETTE, J. "*La Métallographie en Couleurs appliquée à l'examen microscopique des métaux ferreux.*" 8vo. pp. v + 56. Illustrated. Paris, 1938: Librairie Dunod. (Price 38 francs.)

Alternative to "heat tinting," certain reagents in the form of solutions may be used for the "colour etching" of ferrous sections for micro-examination. This booklet gives an account of this technique with special reference to the work of Le Chatelier in developing various suitable reagents. Photographic reproduction of the coloured sections is described and interpretation of the results is briefly discussed. The second half of the booklet lists and describes the constituents of the iron-carbon equilibrium diagram and concludes with some illustrations in colour. Much of the descriptive matter is very elementary, but metallographers will find sundry matters of interest in the various reagents quoted.

I. G. SLATER.

SCHMID, L. "*Der Bau und der Betrieb der Kupolöfen.*" Zweiter Band (Die Betriebspraxis der Eisen-, Stahl- und Metallgiesserei. Herausgegeben von H. Hermanns. Heft 20). 8vo. pp. vii + 235. Illustrated. Halle (Saale), 1937: Verlag von Wilhelm Knapp. (Price 8.62 RM.)

This is one of a series of books dealing with various aspects of metal foundry work, and is the second part of the section concerned with the cupola furnace. The construction of such furnaces was dealt with in the first part, and the present volume covers the method of operation. The subject is divided into four sections, describing respectively the raw materials, the chemical and physical reactions in the furnace, the principles of burdening and the methods of control.

The book is concerned with modern German practice, and details of the raw materials are restricted to those of domestic origin, but this does not detract from the value of the work. In every section the subject-matter is dealt with in a most systematic manner, and one is led to consider the various factors operative in the working of a foundry cupola in a logical succession. The metallic charge, the flux, and the fuel are all considered in detail, and the author has compressed a surprising amount of information into this section. The reactions taking place in the furnace are simply but adequately described, and the heat balance is worked out for various conditions of metal, slag and flue-gas temperature. The third section deals with the metal mixtures used to give different qualities of cast iron, and after a general discussion examples are given of suitable charges for a number of special irons for various purposes. The final section is concerned with the control of the raw materials, the blast, the combustion process, and finally of the product. The author has drawn freely on the published work of others, and a bibliography of 177 papers is included at the end of the volume. As an introduction to the methods of cupola operation, this book can be recommended. STEPHEN L. ROBERTON.

SCHUTZ, E. "*Die Emaillierung des Gusseisens.*" (Die Betriebspraxis der Eisen-, Stahl- und Metallgiesserei. Herausgegeben von H. Hermanns. Heft 23). 8vo. pp. 150. Illustrated. Halle (Saale), 1937: Verlag von Wilhelm Knapp. (Price 6.45 RM.)

Since so much of the output of modern iron foundries finds its way into service as enamelled iron ware, it is proper that a volume on enamelling should be issued in this series of books dealing with all the aspects of foundry technique. The volume under review cannot be considered as an introduction to the subject, as the principles and practice of the art are dealt with very shortly and in a most disconnected way. As an example of the latter feature it may be mentioned that the last section of text in the book deals with the cleaning of castings for enamelling, surely a matter that should have been considered earlier. The author welcomes the adoption of scientific methods by what was formerly an industry based on secrecy, but there is little evidence of scientific principles in the account presented. The outstanding feature of the book is the space allotted to elementary chemical calculations, and to tables of atomic weights, chemical formulæ and constituents of enamel mixtures. This information gives the volume a certain value as a handbook of facts and figures for those engaged in the enamelling industry, but apart from this it is difficult to see for what class of reader the book has been written. It is interesting to note that the author draws attention, in the section on raw materials, to the necessity for economy in imported enamel constituents, and for the wider use of domestic substitutes. Such statements have been frequent of late in German periodicals, but here the principle finds publication in a work of a more permanent character.
STEPHEN L. ROBERTON.

SÉFÉRIAN, D. "*High-Temperature Welding Flames.*" Preceded by a note on the specific heat of gases at high temperatures. Preface by M. G. Ribaud. Translated by N. F. Daniel. 8vo. pp. 51. London, 1937: Penton Publishing Co., Ltd. (Price 3*s.* 9*d.*)

The author, who is Professor at the High School of Autogeneous Welding in Paris, presents a review of the present state of knowledge

concerning such important industrial flames as the oxy-acetylene flame, the atomic-hydrogen flame, the oxy-hydrogen flame, the oxy-methane flame, &c. He deals with the application of the new theory of specific heats to the calculation of flame temperatures. He discusses the composition of high-temperature flames, and the subject of temperature as a function of oxygen concentration. In his conclusions he brings forward the relative usefulness of various industrial flames.

STICHTING VOOR MATERIAALONDERZOEK: Mededeling No. 13. Centrale Corrosie Commissie. "*Derde Verslag van Corrosie Commissie II voor de Bestudering van Buisaantasting door Bodeminvloeden*" Onderwerp: Voorschriften voor de Asfaltering van Buizen met Asfaltibumen van het Geblazen Type. Maart 1937. (Third Report of the Dutch Corrosion Committee II for the Study of the Corrosive Effect of Soils on Pipes. Subject: Regulations for the Asphalting of Pipes with Asphaltic Bitumen of the Blown Type). 8vo. pp. 118. 's-Gravenhage, 1937.

The work of this Committee of the Dutch Stichting voor Materiaalonderzoek, who are engaged in studying the corrosion of pipes in soil, has now proceeded far enough to enable them to draw up specifications for protective coatings based on blown asphaltic bitumens, although they consider that much further work will be necessary before they are able to do this for coatings of tar or non-blown bitumens. These specifications, together with a large number of methods of control testing, are published in the present Report.

After discussing the properties required in a protective coating for pipes and remarking that no simple and cheap coating can be expected to possess all of them, the Committee give specifications for four types of blown asphaltic bitumen coatings for external protection and for two types of similar coatings to be used for the internal protection of water pipes. The external coatings are designed to resist conditions of increasing severity, being graded as light, moderate, heavy and very heavy protection, respectively.

The methods of control testing described in the specifications lay stress on the physical properties of the bitumen itself, *e.g.*, softening point, brittleness and resistance to flow, and on the insulating properties of the complete coating. The tightness of the coating is checked by two electrical methods, a sparking test in which the insulation is tested under a high-tension alternating current, and the measurement of the electrical conductivity of the coating; a chemical test, involving immersion in $N/50$ hydrochloric acid is also specified.

The Committee refer to the effect of the basis metal and distinguish between cast iron and steel in this respect. Differences in the surface condition of cast iron have no unfavourable effect on the coating under any circumstances, but in the case of steel the Committee specify the removal of scale by phosphoric acid pickling for the highest grade of coating, and recommend this procedure in the case of the two intermediate ones.

The Report concludes with some interesting practical observations on the transport of pipes, illustrated by some thirty photographs, which will repay study by those directly interested in the subject. It may be noted that the Committee lay down the condition that the coatings shall satisfy the specifications after delivery, thus rendering the producer responsible for damage in transport. (An English translation of the Report is available in the Library of the Iron and Steel Institute.)

J. C. HUDSON.

MINERAL RESOURCES

(Continued from pp. 49 A–50 A)

Iron Ore and Manganese Resources in South Africa. (Engineer, 1937, vol. 164, Oct. 22, p. 446). The Postmasburg manganese deposits are referred to and the geology and chemistry of the ores discussed. Other manganese deposits in the Transvaal and at Coledon (Cape) are noted. The geology, chemistry and exploitation of the considerable iron ore deposits of South Africa are discussed. The iron ore resources are said to be sufficient to cover an annual export demand of 2×10^6 tons for a long period, and are associated with adequate supplies of coal and other raw materials.

The Ironsands of New Zealand. A. W. Wylie. (New Zealand Journal of Science and Technology, 1937, vol. 19, Sept. 25, pp. 227–244). The author discusses the geology, origin and mineralogical composition of New Zealand ironsands which contain about 50% of iron, 10% of titanium dioxide and also vanadium. Methods of concentrating the sand are noted, and earlier attempts to utilise them for the production of iron and steel discussed in detail, particularly in regard to electrical smelting processes. It is noted that at the present moment increasing quantities of New Zealand ironsand are being shipped to England, where a method of utilising them has recently been successfully developed. The high cost of electrothermal reduction processes is referred to. An account of proposed methods for extracting the vanadium and titanium from the sands concludes the account.

Graphite and its Use in the Metal Industry. A. Humann. (Metallwirtschaft, 1937, vol. 16, Nov. 26, pp. 1250–1252). The author discusses briefly the natural occurrence of graphite and notes the domestic resources of Germany. The use of graphite in foundry practice is considered at some length with particular reference to the suitability of domestic material for this purpose. The applications of graphite in various forms as a lubricant and as a corrosion-resisting pigment are also dealt with.

The Deposits of Crystalline Magnesite and their Distribution in the Mountain Ranges of the Eastern Alps. R. Schwinner. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 306–314). The author discusses in detail the geology and mineralogy of the magnesite deposits in the Austrian Alps.

The Lambrechtsberg (1647–48) and Goding (1696–97) Iron Mines. J. Klausberger. (Montanistische Rundschau, 1937, vol. 29, Dec. 16). A brief historical account is presented of the development and exploitation of iron ore deposits in Lambrechtsberg, Austria.

Early Mining Industries in the Austrian Alps. (Wiener Zeitung: Montanistische Rundschau, 1937, vol. 29, Dec. 16). The prehistoric development of iron ore deposits is referred to.

Report on the Comparative Geological Investigation on Hungarian Coals. E. Vadász. (Report on the Work of the Széchenyi Scientific Society, Budapest, 1937, pp. 53–57). The geological and structural characteristics of coals from Ajka, Mór, Kisgyón, Borsod, Nógrád, Várpalota, Noszlop, Gyöngyös, Felsöborsod, and Hidas are briefly discussed. The abnormal origins of Hungarian coal are commented upon.

The Seventeenth International Geological Congress, Moscow, 1937. R. J. Bridges. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1937, vol. 38, Nov., pp. 211–218). The author refers *inter alia* to the iron ore deposits in the vicinity of Krasnouralsk, the Satka magnesite deposit, the Korkino coalfield (forming part of the Cheliabinsk brown-coal basin), the titanium- and vanadium-bearing magnetite of Kusa (the smelting of which is briefly described), the raw-material supply and plant of the Magnitogorsk steelworks and to the occurrence of nickel and manganese ores in other parts of Russia.

Development of the Magnesite Works in Satka during the First Five-Years Plan. L. Loch. (Berg- und hüttenmänniches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 350–351). The geology and exploitation of the high-grade magnesite deposits of Satka (western Urals, Russia) are discussed.

Iron Ore Mining on Red Mountain, Alabama. T. C. DeSollar. (Mining and Metallurgy, 1937, vol. 18, Nov., pp. 493–497). The author describes the geology and mineralogy of the hematite ores of Red Mountain, Alabama, their development and exploitation, and methods of mining, handling and transport. The preparation of the ores is briefly dealt with.

Coal Deposits of Pike County, Kentucky. C. B. Hunt, G. H. Briggs, A. C. Munyan and G. R. Wesley. (United States Geological Survey, 1937, Bulletin No. 876). The geology of Pike County, Kentucky, is discussed in relation to the location and nature of the coal-beds of the district. Thirteen coal-beds are being exploited commercially, while about forty-eight others are known. The authors give production statistics and analyses in tabular form.

The Bald Eagle Magnesite Mine, California. J. B. Perry and G. M. Kirwan. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 861: Mining Technology, 1938, vol. 2, Jan., No. 1). The authors describe the geology and exploitation of the recently-developed magnesite deposits at the Bald Eagle Mine, California.

The Evolution of Mining in the New Turkey. B. Granigg. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 330–335). The exploitation of ore deposits in Turkey is discussed. Included in the minerals referred to are chromite and coal.

ORES—MINING AND TREATMENT

(Continued from p. 51 A)

Prospecting, Mining and Washing the Brown Iron Ores of Alabama. C. Morgan. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 860 : Mining Technology, 1937, vol. 1, Nov., No. 6). The author discusses the prospecting, mining and washing of low-grade brown iron ore in Alabama. The economic aspects of the industry are discussed, production data presented and some references made to the geology of the deposits.

Progress in the Field of Iron-Ore Dressing. W. Luyken. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 229–233). The author discusses difficulties associated with the concentration of low-grade iron ores in Germany and describes the theory and practice of a new magnetising roasting process involving the initial partial reduction of the ore to the ferrous state at 500° C. to 600° C., followed by re-oxidation at about 500° C. to give γ-Fe_2O_3. Tabular data showing the results obtained are presented. Methods evolved for preparing Siegerland spathic iron ore and the Krupp direct process are also referred to.

On a New Method of Dressing. E. Bierbrauer. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 204–208). A new method of separating coarsely-pulverised mineral mixtures developed at the Montanistische Hochschule at Leoben is described. Known as the " Pick " method, it is based on the selective adherence properties manifested by certain minerals when pressed against a specially prepared adhesive surface under controlled pressure. Such a surface may consist of petroleum pitch.

Scientific and Technical Investigations on the Roasting of Clay-Band Ironstone in the Siegerland. E. Plotzki. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 263–271). Roasting conditions for Siegerland clay-band ironstone were determined in a series of laboratory experiments. Observations on the conditions in practice were made on a tall experimental kiln fitted with special gas-extraction equipment; temperature measurements were made and the gases evolved and the air admitted held under close scrutiny. Heat conservation was found to be improved by thermally insulating and increasing the height of the shaft of the kiln, while careful regulation of charging and of the air supply led to an improved heat balance. Means were devised for increasing the throughput and for converting an intermittent operation to a continuous operation with automatic removal of the roasted ironstone.

REFRACTORY MATERIALS

(Continued from pp. 106 A–107 A)

Silica Refractories : Their Production and Properties. W. J. Rees. (Year Book of the Coke Oven Managers' Association, 1938, pp. 193–207). After a brief discussion on the history of refractories, the author describes the sources and properties of the raw material for making silica brick, the physical and crystallographic characteristics of silica, the grinding of the raw material, the nature and purpose of bonding materials, moulding, drying, and firing practice, and the structure of the finished brick.

Improved Apparatus for Measuring Thermal Conductivity of Refractories at High Temperatures. J. L. Finck. (Journal of the American Ceramic Society, 1937, vol. 20, Nov., pp. 378–382). The author describes an improved form of apparatus for measuring the thermal conductivity of refractories at high temperatures. (*See* Journ. I. and S.I., 1935, No. I., p. 324 A).

Physical Properties of Silicon-Carbide Refractories. H. N. Baumann, jun., and J. P. Swentzel. (Bulletin of the American Ceramic Society, 1937, vol. 16, Nov., pp. 419–430). The physical properties of and engineering data relating to silicon-carbide refractories, particularly of the bonded type containing at least 85% of silicon carbide, are discussed, and the principal ceramic and metallurgical applications of the material are enumerated. Data are presented in tabular and graphical form.

Comparison of the Thermal Conductivity and Thermal Expansion of Coke-Oven Liners made from Eastern and Western Quartzite. J. B. Austin, R. H. H. Pierce, jun., and W. O. Lundberg. (Journal of the American Ceramic Society, 1937, vol. 20, Nov., pp. 363–367). The results of a set of comparative measurements of thermal conductivity carried out on "eastern" and "western" silica coke-oven liners made by the same process show that the latter has a conductivity approximately 15% above that of the former; differences in porosity are responsible for this. Minor variations only were found in the thermal expansion.

Increasing the Life of Blast-Furnace Linings. V. Rybnikov. (Stal, 1936, No. 11, pp. 95–99). (In Russian). The author describes experiences with chamotte bricks pressed pneumatically at pressures up to 600 kg. per sq. cm. Such bricks gave a porosity of 10–15%, a specific gravity of 2–2·1, were resistant at temperatures up to about 1700° C., and withstood without destruction 100–435 thermal cycles as compared with a resistance shown by ordinary chamotte brick of 12–25 cycles.

Recent Steel Plant Experience with Metal Encased Basic Brick. H. S. Robertson. (Steel, 1937, vol. 101, Oct. 11, pp. 99–102).

After comparing the properties of encased and plain magnesite bricks, the author describes the advantages of a new magnesite-chrome refractory encased on two or three sides with mild steel. The service given by this type of brick in open-hearth and electric-furnace practice is highly economical under very severe operating conditions. Data are given regarding field tests.

Mechanically Supported Refractories for Industrial Heating Furnaces. (Industrial Heating, 1937, vol. 4, Oct., pp. 916–922; Nov., pp. 1007–1010; Dec., pp. 1103–1108). Some of the principal designs of mechanically supported refractory arches, including those involving the use of insulating refractories, are described. In conclusion the various designs of suspended walls adapted for use in industrial furnaces are considered.

New Types of Refractories for Open-Hearths. F. Giolitti. (Metal Progress, 1937, vol. 32, Oct., pp. 384, 402). The use of silica refractories for open-hearth furnaces in European practice is noted. "Black dinas" bricks are referred to and their properties and applications discussed. The properties of a new type of silica brick produced in Northern Spain from an agate-like rock and known as "Agata" are commented upon; its softening point is about 1750° C., its specific gravity below 2·35, and its coefficient of thermal expansion lower than that of any other commercial silica brick. Magnesite and magnesite-chromite refractories are dealt with, including a new type of the latter made from the molten slag produced in the manufacture of low-carbon ferro-chromium by the Haglund process. Chromite, magnesite and bauxite are used in the process, the bricks containing about 35% of chromic oxide, 25% of magnesia and 35% of alumina; their melting point is above 2000° C., and they are resistant to the action of both acid and basic slags. Known as "Siemensit," these bricks have proved exceptionally satisfactory in open-hearth furnaces heated by coke-oven gas and operating at very high temperatures. Zircon bricks are also referred to.

Acid Bessemer Refractories. J. H. Chesters and R. J. McLean. (Journal of the American Ceramic Society, 1937, vol. 20, Nov., pp. 373–378). Study of refractories used in the acid Bessemer process has shown that failure of the tuyeres, which generally precedes that of the remainder of the bottom, is due mainly to attack by ferrous and manganous oxides; an addition of 8% of either to the refractory reduces its melting point to 1550° C. Bottom life might be increased by the use of basic tuyeres of high spalling resistance, by the use of graphite tuyeres or by using high-alumina fireclay.

FUEL

(Continued from pp. 108 A–114 A)

Combustion Temperatures of Solid and Gaseous Bodies.—Their Calculation. Kovache. (Arts et Métiers, 1937, vol. 91, Nov., pp. 241–246). The author discusses the calculation of the combustion temperatures of solid and gaseous fuels. Producer-gas and blast-furnace gas (without regeneration) are considered in some detail.

Combination-Fired Boilers at Carnegie-Illinois Steel Corporation. C. H. Williams. (Iron and Steel Engineer, 1937, vol. 14, Nov., pp. 43–61). The boiler plant at the Ohio Works of the Carnegie-Illinois Steel Corp. is discussed in detail. Steam is generated in the boilers recently installed at 525 lb. per sq. in. and at 700° F. total temperature. Firing is by means of blast-furnace gas in combination with and enriched by pulverised coal. The mechanism of the fuel mixing and controlling equipment is discussed and the characteristics of the plant are examined.

New Power Station for Steel Mill. (Steel, 1937, vol. 101, Dec. 27, pp. 45–46). An account is given of steam generating plant and electrical generator equipment being installed at the South Works, Chicago, of the Carnegie-Illinois Steel Corp. Operating and power-production data are included in the description.

Large Steelworks Extensions. (Electrical Review, 1937, vol. 121, Dec. 10, pp. 809–812). An account is given of the electrical generating plant and distributing system at the Cleveland Works of Messrs. Dorman Long and Co., Ltd. The power consumption of the works approaches 2×10^6 kWh. per week. Motors of from 100 to 500 h.p. operate in general on current at 2750 V.; smaller motors are supplied with current at 440 V. The electrical equipment in the new merchant mill is described at some length.

Weirton Installs 800-lb. Super-Imposed Turbine Generator. J. H. Strassburger. (Blast Furnace and Steel Plant, 1937, vol. 25, Nov., pp. 1191–1195, 1232–1233). The author presents an account of the 10,000-kW. turbo-generator operating at 825 lb. per sq. in. and 820° F., recently installed at the Weirton plant of the Weirton Steel Co. Tabular data and a flow sheet are included in the account.

Electrical Control Gear for Ebbw Vale Iron and Steel Works. (Iron and Coal Trades Review, 1937, vol. 135, Oct. 29, pp. 700–701). **Electrical Control Gear for Ebbw Vale.** (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 58–60). (*See* p. 64 A).

Fuel Control in the Iron and Steel Industry. M. Koopman. (Newport and District Metallurgical Society, Nov. 6, 1937 : Journal of the Institute of Fuel, 1937, vol. 11, Dec., pp. 146–152 : Iron and Steel Industry, 1937, vol. 11, Dec., pp. 95–102). (*See* p. 10 A).

Waste Heat Boilers at Dearborn. C. G. Bigelow. (Freyn Design, 1937, Dec., No. 12, p. 18). Open-hearth furnaces Nos. 1, 2 and 3 at the Dearborn plant of the Ford Motor Co. are equipped with Freyn-Design waste-heat boilers 12 ft. in dia. The construction and operation of the boilers are discussed.

Waste-Heat Boilers in the Steel Industry. A. F. Webber. (Journal of the Institute of Fuel, 1937, vol. 11, Dec., pp. 81–84). The author discusses the development of the waste-heat boiler and its utilisation for the efficient recovery of "low-grade" heat in steelworks. The application of such boilers to the recovery of waste heat from open-hearth furnaces and problems associated with their use are discussed at length. The fire-tube waste-heat boiler is dealt with, and the calculation of steam production from a given open-hearth furnace is considered. Future developments are noted.

Waste Heat Boilers. W. Gregson. (Journal of the Institute of Fuel, 1937, vol. 11, Dec., pp. 84–89). The author discusses fundamental principles in the design of waste-heat boilers. Various types of boiler are described.

Waste-Heat Recovery Using Thimble-Tube and Water-Tube Boilers. E. F. Spanner. (Journal of the Institute of Fuel, 1937, vol. 11, Dec., pp. 89–94). Having dealt briefly with the purpose and scope of waste-heat recovery for steam-raising purposes, the author discusses the difficulties encountered due to the high temperature and corrosive nature of the gases involved, and to the varying specific gravity of such gases. Water-tube waste-heat boilers for Diesel engines are also referred to.

Waste-Heat Recovery in Gas-Works Practice. J. W. Reber. (Journal of the Institute of Fuel, 1937, vol. 11, Dec., pp. 95–96). The author presents a general survey of waste-heat recovery practice in gas works, emphasising in particular the economy in heat which such practice renders possible. Graphical data are presented.

Development of Steam Generation from Gas Engine Exhaust. T. A. Lewis. (Steel, 1937, vol. 101, Nov. 1, pp. 62–67). The author describes the development of waste-heat boilers utilising the sensible heat of gas-engine exhausts, with particular reference to such plant at the Bethlehem Steel Co. (*See* p. 109 A).

Petrology and the Classification of Coal. C. E. Seyler. (Proceedings of the South Wales Institute of Engineers, 1938, vol. 53, Jan. 13, pp. 254–305). The author discusses the petrology of coal and systems of classification. The techniques of petrological analysis are considered at length and results are presented and compared for a number of different coals.

A Hoyois Washery at Smithy Wood Colliery. (Colliery Engineering, 1937, vol. 14, Dec., pp. 405–410). Structural and operating data and output figures are presented for the Hoyois washer installed at Smithy Wood Colliery. The plant can handle 150 tons per hr.

Innovations in the Preparation of Bituminous Coals in 1936. A. Götte. (Glückauf, 1937, vol. 73, Dec. 11, pp. 1121–1131; Dec. 18, pp. 1145–1149; Dec. 25, pp. 1174–1180). The author presents a comprehensive review of progress in coal cleaning and grading methods and practice in 1936.

The Development of Pneumatic Methods of Coal Cleaning. C. Berthelot. (Génie Civil, 1937, vol. 111, Dec. 25, pp. 541–544). The advantages of pneumatic cleaning methods for coal are summarised and the Birtley process and plant are described in detail, with particular reference to the installation at la Compagnie des Mines de Marles (Pas-de-Calais).

Progress in By-Product Coking in 1937. (Coal Carbonisation, Supplement to Colliery Engineering, 1938, vol. 4, Jan., pp. 5–12). A review is presented of the development of the demand for coke during 1937 and of possible lines of expansion in the future. The activities of various coke-oven-constructing firms during the past year are illustrated by descriptions of plant which they have recently erected in England and abroad. Operating data and output figures are given for these plants.

The Mechanical Side of a By-Product Coking Plant. J. Arrowsmith. (Year Book of the Coke Oven Managers' Association, 1938, pp. 250–253). The author discusses briefly some essential considerations in the designing, erection and running of by-product coking plant.

Heat Utilisation in Carbonising Plants. J. W. Reber. (London and Southern District Junior Gas Association: Gas Journal, 1937, vol. 220, Dec. 22, pp. 927–934). The author considers the heat distribution in carbonising plants from the initial reactions involved in the production of producer-gas for heating the ovens to those which characterise the combustion of the gas. The account deals also with the heat required to carbonise coal and with methods of utilising the surplus heat in the most economical manner.

Carbonisation by Electricity. G. J. Greenfield. (Gas World, Coking Supplement, 1937, vol. 107, Dec. 4, pp. 137–138). The author describes the construction and operation of an experimental electrical carbonisation plant installed by the Detroit Edison Company. The advantages and disadvantages of the process are critically reviewed, particular attention being paid to energy consumption and cost.

The Manufacture and Economics of Concentrated Gas Liquor as Applied to Coke-Oven By-Product Recovery Plant. J. Bishop. (Year Book of the Coke Oven Managers' Association, 1938, pp. 122–136). The author describes condensing and concentrating plant for handling gas liquor in by-product recovery plant attached to coke-ovens. The operating expenses of such equipment are analysed in detail and reference is made to practice at various works.

Low-Temperature Coke from Bituminous Coals as Raw Material for Chemical and Metallurgical Processes. W. Demann. (Glückauf,

1937, vol. 73, Dec. 4, pp. 1101–1106). The aims and advantages of low-temperature coal carbonisation are discussed, and the possible applications of the coke produced considered at length. The results of large-scale experiments on the utilisation of the gaseous by-products for producing oil by hydrogenation and the use of the coke for the production of ferro-silicon are discussed in detail.

Low-Temperature Coke from Bituminous Coals as Gas-Producing Fuel in Fixed Gas Producers. E. Rammler. (Glückauf, 1937, vol. 73, Nov. 27, pp. 1077–1088; Dec. 4, pp. 1106–1112). The author discusses the results of extensive experiments (the apparatus and technique employed being described) upon the utilisation of low-temperature coke in gas producers of the non-portable type. Conditions affecting the operation of the plant, thermal considerations, gas output and composition, dust content of the gas, and the particular advantages of low-temperature coke as fuel for gas producers are among the aspects considered. (*See* p. 113 A).

Gas Conditioning Advances with Consumer Demand. O. R. Rice. (Freyn Design, 1937, Dec., No. 12, p. 21). A brief description is given of equipment for cleaning blast-furnace gas. Cyclone moisture eliminators, electrostatic precipitators and Theisen disintegrators are referred to.

Changing Fuels in the Steel Mill. J. B. Nealey. (Steel, 1937, vol. 101, Dec. 13, pp. 58–61, 82). The author describes the conversion of reheating and annealing furnaces in the Toronto (Ohio) and Follansbee (W. Va.) works of Follansbee Bros., from producer gas, coal or oil firing to natural gas. The advantages derived from the conversion are discussed at length, as regards both cost and quality of work and maintenance expenses.

The Operation of Coke-Oven-Gas-Fired Open-Hearth Furnaces with Increased Addition of Pulverised Lignite. C. Kreutzer. (Stahl und Eisen, 1937, vol. 57, Dec. 16, pp. 1397–1403). After a brief reference to difficulties experienced in connection with the wear of checkers in earlier attempts to employ coke-oven gas carburetted with pulverised lignite for heating open-hearth furnaces, the author describes the results of experiments with gas so carburetted and fed through specially designed ports. Difficulties encountered in the checkerwork were traced to slagging-up of the lower layers of checkers, this leading to accumulations of dust in the upper part of the checkerwork. By designing the brickwork to give passages for the gas which increased in size towards the lower part of the regenerative chamber, such dust accumulation was prevented. Analysis showed the dust to be strongly basic; a high-alumina checker brick was therefore employed in the upper part of the chamber, thus decreasing the formation of fusible reaction products, whilst, in addition, the lower checker bricks were made smaller in size than the upper, thus allowing a greater space for dust to accumulate without interfering with the passage of the gas and so causing alterations in the form of the flame and leading to the

damaging of the furnace refractories proper. Removal of dust from the checkers and melting out of any deposits of reaction products results in increased life for the checkerwork. The economies effected by the procedure outlined are discussed at length.

Carburetting with Pit-Coal Pitch and Tar Oil in Open-Hearth Furnaces Fired with Cold Coke-Oven Gas. (Stahl und Eisen, 1937, vol. 57, Dec. 30, pp. 1449–1452). Reports are presented from five open-hearth furnace plants which indicate the possibility of achieving satisfactory carburetting not only with pulverised brown coal but also with pitch/tar-oil mixtures containing at least 65% of pitch and, in two plants, with 100% pitch. Investigations on atomisation with heated compressed air appear to yield particularly valuable results, as a method is provided in this way of carburetting with pitch/tar-oil mixtures or with pitch alone even in plants possessing no available steam for atomising purposes. The use of preheated compressed air in place of steam is expected to assist in solving the difficulty of maintaining the stability of the roof experienced when steam is used. (*See* p. 56 A).

Combustion Efficiencies of Gas and Oil Engines. W. A. Tookey. (Journal of the Institution of Civil Engineers, 1937, Dec., pp. 166–190). The author discusses problems in connection with the combustion efficiencies of gas and oil engines as determined by means of the Tookey factor. The derivation of this factor is explained, and tests on engines under a variety of operating conditions and with mixed and unmixed gases are described.

Coal Hydrogenation. H. H. Storch. (Industrial and Engineering Chemistry, 1937, vol. 29, Dec., pp. 1367–1371). A discussion is presented of the relative importance of the rank of coal, nature of vehicle, type of catalyst, agitation, temperature and pressure in coal hydrogenation. Velocities of reactions and equilibria are considered in dealing with the mechanism of the reactions involved.

Primary Liquefaction by Destructive Hydrogenation of the Oxygen, Nitrogen and Sulphur Linkages. C. H. Fisher and A. Eisner. (Industrial and Engineering Chemistry, 1937, vol. 29, Dec., pp. 1371–1376). In order to obtain information regarding the elimination of inorganic elements in the coal substance during the primary liquefaction stage in the hydrogenation of coal, a Pittsburgh bed coal was hydrogenated in tetrahydronaphthalene for periods of 3, 6, 9 and 12 hr., at 385°, 400° and 415° C. During the first 3 hr., 60% of the oxygen was eliminated; the remainder was removed with much greater difficulty. It appears that two types of oxygen linkage are present in coal. Nitrogen elimination was slow and approximately constant. Sulphur removal was also slow, and occurred mainly in the first 3 hr. Tentative conclusions are advanced concerning the mechanism of primary liquefaction and the nature of the oxygen linkages in coal.

PRODUCTION OF IRON

(Continued from pp. 115 A–116 A)

Second Blast Furnace at Pretoria. (Freyn Design, 1937, Dec., No. 12, p. 7). A description is given of the construction and auxiliary equipment of a blast-furnace recently installed at the Pretoria Works of the South African Iron and Steel Industrial Corporation. The furnace has a hearth diameter of approximately 16 ft. and is capable of producing about 575 tons of iron per day.

The S.K.F. Plant at Hofors. D. D. Howat. (Iron and Steel Industry, 1937, vol. 11, Dec., pp. 79–84). The author describes the plant, plant layout and production of the Aktiebolag Svenska Kullagerfabriken, Hofors, Sweden. The equipment comprises plant for concentrating ores, most of which come from the Company's own mines at Longnes, near Hofors, two blast-furnaces for producing charcoal pig, seven open-hearth furnaces, and rolling mills, piercing machines for tube manufacture and rod mills.

Operating Results in Soviet Plants. (Freyn Design, 1937, Dec., No. 12, pp. 8–9). Blast-furnace and open-hearth production figures for a number of Soviet plants and data respecting a new standard blast-furnace with a 26 ft. 3-in. dia. hearth are presented.

Armco Builds Furnace at Hamilton. B. E. Tau. (Freyn Design, 1937, Dec., No. 12, pp. 4–6). An account is given of the construction of a new 500-ton blast-furnace at the Hamilton plant of the American Rolling Mill Co. This furnace was constructed largely from components and units taken from obsolete plant.

Bell Operation with High Top Pressure. O. R. Rice. (Freyn Design, 1937, Dec., No. 12, p. 22). The construction and mode of operation of a by-pass valve for equalising the gas pressure on the upper and lower sides of blast-furnace bells, thus facilitating rapid opening of the latter, are described.

Coke Charged Automatically. A. J. Whitcomb. (Freyn Design, 1937, Dec., No. 12, p. 20). The construction and operation of an automatic electrically-actuated coke weighing control system installed on a blast-furnace are described.

Performance of S.S. Stoves. J. C. Hayes. (Freyn Design, 1937, Dec., No. 12, pp. 14–15). Data are presented regarding the operation and capacity of hot-blast stoves lined with S.S. checkers. The type dealt with is 21 ft. in dia. and 128 ft. high.

Development of the Dressing by Smelting of Low-Grade Ores on the Basis of Calculated Economy in Heat and Power. E. Sentfer. (Stahl und Eisen, 1937, vol. 57, Dec. 9, pp. 1373–1381). The preparation of low-grade iron ores by a smelting technique in the blast-furnace is discussed. Thermal considerations show that a

low coke consumption would be required if experiences gained in normal blast-furnace practice were made use of; the required conditions are examined. It is pointed out that the quality of the metal produced by such a process is a secondary consideration. It is also suggested that plant for pre-smelting treatment should be set up near the ore deposits, the metal produced serving as a type of scrap raw material for existing blast-furnace plants and assisting in increasing their outputs, or, assuming it were of the correct composition, being employed for direct conversion into steel.

The Use of Oxygen in Metallurgical Processes. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 171–172, 176). An English translation of an article by R. Durrer which appeared originally in Stahl und Eisen, 1937, vol. 57, Oct. 7, pp. 1118–1119. (*See* p. 8 A).

The Iron Industry in Brazil. L. Ensch. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 217–220). An account is presented of the Brazilian iron and steel industry. The ores exploited are canga, itabirite, jacutinga and hematite. At the plant of the Companhia Siderurgica Belgo-Mineira S.A. charcoal is used in the blast-furnaces and blast-furnace gas enriched with heavy oil in the open-hearth furnaces.

The Chinese Iron Industry and the Luxemburg Engineer in China. E. Ruppert. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 225–246). An account is presented of the Chinese iron and steel industry, its development, resources of fuel and ore, production and economic status.

South Wales Institute of Engineers. A Brief Historical Note on the Area Covered by its Activities—Especially Merthyr Tydfil, the Place of its Birth, Eighty Years Ago. D. E. Roberts. (Proceedings of the South Wales Institute of Engineers, 1937, vol. 53, No. 3, pp. 176–192). Among the subjects dealt with by the author is the development of the South Wales iron industry, which is somewhat briefly discussed in the introductory part of the paper. Among the data presented are figures regarding the number of furnaces in blast during the latter half of the eighteenth century and output figures. Reference is made to contemporary operating conditions and to production and running costs. Brief mention is made of the development of the tinplate industry and to the work of Cort.

Sussex Yron and Gonnes. C. W. Ford. (Journal of the Royal Artillery, 1937, vol. 64, Oct., pp. 367–374). An historical account is presented of the Sussex iron industry from pre-Roman times until its decline in the latter part of the eighteenth century.

Investigation of the Chattish Iron Find. J. W. Gilles. (Stahl und Eisen, 1938, vol. 58, Jan. 20, pp. 61–62). Brief notes are presented on the metallography and composition of certain iron objects dating from about 100 B.C. and discovered prior to the Great War at Altenburg (Niedenstein), Germany. The indications of welding and heat treatment and the high phosphorus content of the metal (0·23%) are referred to.

FOUNDRY PRACTICE

(Continued from pp. 117 A–120 A)

A Foundry Cuts Power Cost. G. Fox. (Freyn Design, 1937, Dec., No. 12, pp. 16–17). Details are given regarding economies effected in an American foundry employing electric melting furnaces and a large number of electric motors by the installation of power-factor-correction equipment.

Operating a Cupola. H. W. Kelly. (Foundry, 1937, vol. 65, Dec., pp. 37, 86). An account is presented of a satisfactory foundry layout and of a method of operating and lining a cupola suitable for a production of about 40 tons of metal per day. Reactions occurring in the cupola are briefly outlined.

How Shall I Slag my Cupola? D. J. Reese. (Foundry, 1937, vol. 65, Nov., pp. 36–37, 96). The author discusses the purpose and effect of the slagging operation in cupola practice. The refining and cleaning action of the slag is examined and two methods of carrying out the slagging process are briefly described. The mechanism of the erosive action of slags upon the slag hole is considered with particular reference to modern cupola practice, which employs heavy percentages of steel in the charge. A detailed discussion of the slagging operation in practice concludes the article.

Experience with Balanced Blast Cupola. W. L. Roueche. (Iron Age, 1937, vol. 140, Dec. 2, pp. 43–46). The author reports on the performance of two balanced-blast cupolas installed by the McWane Cast Iron Pipe Co., Birmingham, U.S.A. These were, before their conversion to the (66-in.) balanced-blast type, of the conventional (72-in.) type; performances before and after conversion are compared. Tabular and graphical data are presented.

Metal Melting in the Iron Foundry. L. W. Bolton. (Proceedings of the Staffordshire Iron and Steel Institute, 1936–37, vol. 52, pp. 103–111). The author discusses furnaces for metal melting in the iron foundry. Crucible and air furnaces, electric furnaces of various types, rotary furnaces for use with solid fuel, pulverised coal and oil, and the cupola are considered, together with their thermal characteristics and the nature of their influence upon the chemical composition of the melt. Metal and operating costs are tabulated and compared for cupola, direct arc furnace and rotary furnace melting practice.

Rapid Annealing Cycle is Feature of Malleable Plant. (Foundry, 1937, vol. 65, Nov., pp. 32–34, 92, 96). An account is presented of the rapid malleablising cycle utilised in the Saginaw Malleable Iron Division of General Motors Corporation. The shaking-out and cleaning of the castings prior to annealing are described. Annealing is carried out in a continuous tunnel kiln heated by gas-fired radiant

tubes; the tunnel kiln is 360 ft. long, and is described in detail as regards both construction and operation. The development of iron suitable for an annealing treatment of 30 hr. is briefly recounted. Fifty-five tons of malleable castings are produced per day.

Automotive Malleable Castings Made on Continuous Molding Units. E. Bremer. (Foundry, 1937, vol. 65, Oct., pp. 32–33, 92). An account is given of the *A* unit in the moulding department of the Saginaw Malleable Iron Division of the General Motors Corporation. This unit forms one of three, all of which operate on the continuous principle. Much of the equipment is fully automatic. An account of the melting and casting techniques employed is included.

Synthetic Moulding Sand. H. Reininger and H. Jensch. (Giesserei, 1937, vol. 24, Dec. 3, pp. 617–623; Dec. 17, pp. 649–654). In the first part of this article the authors deal with the principles governing the production of synthetic moulding sand and its properties. The structure and properties of natural moulding sands are first considered, the shortage of such sands, their deterioration in use in the foundry and their reclamation by daily additions of new sand being examined. Certain fundamental properties of synthetic sands are discussed and the function of bonding agents is dealt with. In the second part of the article the organised production of synthetic sands is treated in detail. The significance of grain-size distribution in connection with the structure of sand masses is dealt with together with methods of restoring the plastic properties of used sand. The commercial production of synthetic sand by the " Geko " method and the properties of the sand for iron foundries so produced are considered at length; the properties of commonly used grades of sand are compared with those of this synthetic sand.

Naturally-Bonded or Synthetic Moulding Sands? A. Tipper. (Institute of British Foundrymen: Foundry Trade Journal, 1937, vol. 57, Dec. 23, pp. 492–494). The author discusses the choice of moulding sands and factors governing it. The constitution of sand and the nature of sand grains are considered together with certain fundamental physical properties such as grain-size distribution and the surface condition of the grains. Bonding materials are dealt with and the expansion characteristics of clays are examined. Tabular data are given on the compositions and grading of synthetic and natural moulding sands.

Cement Used as a Binding Agent in Grey Iron Foundry. P. Dwyer. (Foundry, 1937, vol. 65, Nov., pp. 24–26, 80–83). The author describes the Randupson process for making moulds as practised in the foundry of the Chambersburg Engineering Co., Inc., Chambersburg, Pa., which is engaged in the production of grey-iron castings. Portland cement is employed as the binding agent for the sand in this process; in the account presented, particular attention is paid to the preparation of the sand. It is noted that,

with the exception of certain small sizes, all cores are made in cement-bonded sand.

Action of Jolt-Type Moulding Machine. S. Tanaka. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, Aug., pp. 273–281). The author presents the results of a detailed investigation of the operation of an experimental jolt-type moulding machine and of the conditions affecting its working. The distribution of mould hardness with and without patterns and the use of jolt-squeeze machines are dealt with. Graphical data are presented.

The Production of Some Intricately-Cored Iron Castings. T. R. Harris. (Institute of British Foundrymen : Foundry Trade Journal, 1937, vol. 57, Dec. 23, pp. 485–487, 494). The author notes briefly the development of the need for the intricately-cored casting and as an example describes the production of the low-pressure cylinder of a two-stage air compressor. Moulding, core assembly and casting procedure are dealt with. The production of a water-cooled casing is similarly described and analysed.

Manufacture and Use of Iron and Steel Rolls. W. H. White and F. L. MacQuarrie. (Iron and Steel Engineer, 1937, vol. 14, Nov., pp. 14–35). In the first part of this paper, W. H. White discusses the manufacture of iron and steel rolls; the compositions of suitable irons, moulding practice, melting and pouring practice, roll turning and rolls cast from alloy irons are dealt with. In the second part of the paper, F. L. MacQuarrie considers the uses of rolls, the mechanics of the rolling process, the quality of the product in relation to the rolling practice employed, and rolling defects.

Makes Diesel Engine Castings. J. E. Olson and E. J. Carmody. (Foundry, 1937, vol. 65, Dec., pp. 30–32, 83). An account is given of moulding, melting, and casting practice employed in the production of Diesel engine components.

Foundry Work on High-Chromium Iron Castings. J. Sissener. (Metal Progress, 1937, vol. 32, Oct., pp. 521–527). The author presents an account of foundry technique in connection with high-chromium iron castings with particular reference to practice in a Norwegian foundry, where an alloy containing chromium 28–30%, nickel 2·5%, carbon 0·7%, silicon 0·7% (max.), molybdenum 0·3–1·0% and titanium or nitrogen as a grain-refining agent is commonly employed; alloys of different compositions are also noted. Melting and casting practice, the mechanical, chemical and machining properties of the alloys, heat treatment and pickling of the castings and observations on American practice are also dealt with at length.

Invisible Shrinkage in Castings. H. A. Schwartz. (Foundry, 1937, vol. 65, Nov., pp. 27, 90). The author discusses the occurrence and detection of microscopic voids, more or less uniformly distributed in iron castings. Such iron shows no macroscopic shrinkage cavities, and the microscopic pores present are too small and diffuse to be detected by X-rays; their existence, however, is confirmed

by estimating the density of the casting as a compact mass and in the form of broken fragments, the method of carrying out this test being described. The mechanism of the formation of microscopic voids is discussed together with the effect of carbon on their occurrence.

Wasters—Their Cause and Cure. V.—Wasters Due to Core-Making. (Iron and Steel Industry, 1937, vol. 11, Dec., pp. 91–94). A continuation of a previous series of articles (*see* p. 120 A). The author discusses the necessity for the artificial venting of moulds, the use of ashes for venting, defects caused by the use of unsuitable core sands and difficulties occasioned by unsatisfactory grids.

Research and Control in Steel and Malleable-Iron Foundries. K. Roesch. (Giesserei, 1937, vol. 24, Dec. 31, pp. 668–672). The author presents a general discussion on the organisation of a foundry testing department and the problems confronting it. The need for constant control is stressed and the value of large-scale research is considered. The development of new types of casting alloys is discussed.

Costing. A. Klemenz. (Giesserei, 1937, vol. 24, Nov. 19, pp. 582–589). A detailed discussion is presented on foundry costing systems.

PRODUCTION OF STEEL

(Continued from pp. 121 A–122 A)

Improvements in the Production of Steel. J. W. Jones and N. I. B. Williams. (Journal of the Institution of Production Engineers, 1937, vol. 16, Dec., pp. 632–646). The authors discuss steelmaking processes, inherent defects in steel, the routine of steelmaking, the structure and mechanical properties of steel, grain size, grain-size control and the influence of grain size on hot-working, the mechanical testing of steel, and the trend of improvements in steel production.

Stainless Steel Plant Doubles Production Capacity. (Wire and Wire Products, 1937, vol. 12, Nov., pp. 707–709, 740). An account is presented of the new melting and rolling equipment for stainless steel installed by the Rustless Iron and Steel Corporation, Baltimore, Md. The capacity of the plant is now estimated at 40,000 tons of stainless-steel ingots and 12,000 tons of re-rolling and forging billets and hot- and cold-finished bars and wire per annum. The rolling practice for stainless steel is briefly outlined and reference is made to wire-drawing

Stainless Steel is Barium's Speciality. T. W. Lippert. (Iron Age, 1937, vol. 140, Dec. 9, pp. 50–55). The equipment, and melting, heat treatment and rolling practice of the Barium Stainless Steel Corp., Canton, Ohio, are described. High-chromium and nickel-chromium stainless steels are produced. The source of power and details of ancillary equipment are also noted.

Crucible Toolsteel. H. C. Bigge. (Metal Progress, 1937, vol. 32, Dec., pp. 773–775). The author presents an account of the technique of crucible tool steel production preceded by a brief review of the development of the process in England and in America.

Contribution by Engineers of Luxemburg to the Application of the Basic Bessemer Process in Russia. L. Mayer. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 221–224). Reference is made to special difficulties encountered in developing a basic Bessemer technique for utilising Kertsch ores.

Studies on the Equilibria of the Dephosphorisation and Desulphurisation Reactions in the Basic Bessemer Process as a Function of the Lime Additions. J. Welter. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 306–314). By means of experiments carried out upon a number of melts, the lime additions to which varied within very wide limits, the influence of such additions and of the basicity of the slag upon the difficulty of dephosphorisation and the degree of desulphurisation in the basic Bessemer process was determined empirically. Results are presented in the form of curves giving mean values. A simple expression is derived to indicate the difficulty of dephosphorisation; for any given degree

of dephosphorisation the iron concentration of the slag diminishes at first very rapidly, then more slowly as the basicity of the slag increases. For each charge an optimum lime addition may be found with which the total loss of iron oxide will be a minimum. The ratio of the sulphur in the slag to that in the metal increases with increasing basicity of the slag; desulphurisation also increases with increasing basicity to a maximum of 48% at 20% (approx.) basicity. The amount of lime necessary to desulphurise a melt containing more than 0·065% of sulphur is greater than that required to produce satisfactory dephosphorisation. Any diminution of basicity—for example, that resulting from the addition of siliceous sand to the converter—increases the loss of iron by oxidation and diminishes simultaneously the degree of desulphurisation.

The Development and Construction of the Open-Hearth Steel Melting Furnace. A. H. Johnson. (Proceedings of the Staffordshire Iron and Steel Institute, 1936–37, vol. 52, pp. 143–154). After a brief historical introduction the author discusses the construction of the modern open-hearth furnace. Blocks, front and back walls, regenerators, relative sizes of gas and air regenerators, slag pockets, flues, valves and ports, the laboratory of the furnace, the roof, chimney flues and chimney, cooling devices and furnace control are each considered under separate heads and dealt with in detail.

Principles of Design of the Basic Open-Hearth Furnace. L. Bruno. (Metallurgia Italiana, 1937, vol. 29, Dec., pp. 649–674). The author presents a study of the mathematics and physics of basic open-hearth design from the standpoints of potential output, the quality of the product obtained and the life of the furnace structure. Graphical and tabular data are given.

Non-Cooled Furnace Valves are Installed at Open Hearths, Heating Furnaces, Glass Tanks. E. H. Koenig. (Freyn Design, 1937, Dec., No. 12, p. 19). Various applications of the Freyn-Fahrite non-cooled furnace valves are briefly referred to, including the reversing dampers employed on two open-hearth furnaces at the Ford Motor Co.'s plant. Brief structural details are given.

Carbon Dioxide Used in Cartridge for the Removal of Slag. C. Cavanagh. (Blast Furnace and Steel Plant, 1937, vol. 25, Oct., pp. 1099–1100). The author describes the construction and mode of operation of the Cardox cartridge and the technique of employing it for assisting in the removal of slag and cinders from open-hearth slag pockets.

On the Use of Bauxite in the Basic Open-Hearth Furnace. F. H. Schönwälder. (Stahl und Eisen, 1937, vol. 57, Dec. 9, pp. 1381–1382). The author discusses the replacement of fluorspar by bauxite of German origin containing much iron and silica for obtaining the fluid slag required for desulphurisation in the basic open-hearth furnace. The composition of a German bauxite is given and the mechanism of its desulphurising action is briefly differentiated from

that of fluorspar. Experiments show that additions of washed German bauxite are perfectly satisfactory unless very low sulphur contents are required, when small additions of fluorspar may be made. Reference is made to the importance of controlling the silica content of bauxite used for the purpose described.

Innovations in Open Hearth Design Permit Continuous Operation. (Steel, 1937, vol. 101, Nov. 8, pp. 61–64). Modifications introduced by Lindemuth in a 170-ton open-hearth furnace recently installed by the Australian Iron and Steel Co., Port Kembla, New South Wales, Australia, permit continuous operation for periods up to five years. The innovations are concerned primarily with checker control. The checker temperature can be determined visually by the furnace operator; furthermore, special facilities are provided for rapid and frequent cleaning of the checkers.

Extensive Control a Feature of Open-Hearth Practice at Lackawanna. P. F. Kinyoun. (Mining and Metallurgy, 1937, vol. 18, Oct., pp. 459–462). An account is presented of the open-hearth department and the control system in use at the plant of the Bethlehem Steel Co., Lackawanna, New York. Six 150-ton furnaces recently installed are designed for coke-oven-gas firing or fuel-oil firing alternatively; these furnaces are described at some length. Reference is made to the "VisControl" method of estimating slag viscosity which was developed by the Company.

Advances in Carbon Steel Manufacture and Application. R. W. Simon. (Metal Progress, 1937, vol. 32, Oct., pp. 431–437, 444). The development of carbon steels of controlled quality is discussed, and various factors influencing the quality and methods employed for determining such factors are considered. Open-hearth slag control is dealt with in detail. Improvements effected in the working qualities of rimming and free-cutting steels are examined, the part played by increased control during the manufacture of the raw material being stressed. New and improved methods of heat treatment have been evolved. The respective uses of carbon and alloy steels are discussed in the concluding pages of the article.

The Low-Frequency Induction Furnace. (Foundry Trade Journal, 1937, vol. 57, Dec. 30, pp. 501–503). The principles underlying the construction of the Russ low-frequency induction furnace, its special properties and the present status of its technical development are discussed. The low melting losses and labour costs entailed in use are referred to, and operating results on some non-ferrous alloys are considered.

Present Tendencies in the Manufacture of Special Steels in France. L. Guillet. (École des Hautes Études Techniques de Prague: Génie Civil, 1937, vol. 111, Dec. 4, p. 482). The author refers briefly to the methods employed in France for the manufacture of the special steels, including the Ugine-Perrin method. The steels are then considered according to their particular properties or uses; structural steels containing low copper or aluminium contents are

noted, together with corrosion- and heat-resisting steels of normal and special compositions.

New Plant Makes Electric Steel. G. Fox. (Freyn Design, 1937, Dec., No. 12, pp. 1–3). An account is presented of the steelmaking plant, rolling mill and rod mill of the North-Western Barb Wire Co., Sterling, Illinois. Two Lectromelt electric furnaces handling 15-ton heats are used in the steelmaking shop. The layout of the casting and rolling departments and operating data are given.

Arc Furnace Melting Costs. A. J. G. Smith. (Iron and Steel Industry, 1937, vol. 11, Nov., pp. 61–62). The melting costs for a 3-ton, basic-lined arc furnace operating in a German works are analysed and discussed. The Demag basket-charger is said to enable outputs to be increased.

Refining Steel in the High-Frequency Furnace. V. Stobie. (Institute of British Foundrymen, Dec. 11, 1937 : Foundry Trade Journal, 1937, vol. 57, Dec. 23, pp. 489–491). The author discusses the operation of the normal high-frequency furnace and considers the causes of its being unsatisfactory for steel refining. The construction and operation of a specially designed high-frequency furnace for refining are described. The refining process in the furnace is described and examined from a metallurgical standpoint, particular reference being made to changes in the composition of the slag during refining and to the carbon monoxide equilibrium. Finally economic factors are considered.

FORGING, STAMPING, AND DRAWING

(Continued from pp. 124 A–125 A)

Modern and Diversified Equipment Employed at Transue and Williams. W. C. Kernahan. (Heat Treating and Forging, 1937, vol. 23, Sept., pp. 454–460). An account is presented of the plant and auxiliary equipment of Transue and Williams Steel Forging Corp., Alliance, Ohio. This corporation specialises in forgings of all types; the plant has a capacity of 3000 tons per month in sizes from 1 oz. to 1000 lb. The account includes a detailed description of the heat-treatment department.

Heavy Forgings. W. H. Hatfield. (Sheffield Society of Engineers and Metallurgists, Oct. 18, 1937 : Iron and Steel Industry, 1937, vol. 11, Nov., pp. 73–75). The author describes the melting and casting technique required for the production of heavy forgings, and discusses the structure of the ingots. Reheating and heat treatment are also dealt with.

Large Steel Forgings. W. H. Hatfield. (Rugby Engineering Society : Iron and Coal Trades Review, 1937, vol. 135, Dec. 17, pp. 1010–1011). After a brief description of the processes involved in the solidification of molten steel, the author describes the scientific control exercised on the freezing process in order to attain the desired mechanical properties in the finished product. Heterogeneity and the effect of mass are also dealt with.

Improvements in Forging Methods. A. M. Steever. (Metal Progress, 1937, vol. 32, Oct., pp. 413–418). The author discusses the development of the modern rigid drop forging hammer and the improvements effected in work carried out with it. Parallel improvements in reheating furnaces are considered; gas fuel is finding increased use together with equipment for temperature and atmosphere control. Simultaneously improvements have been effected in combustion chamber and burner design and in maintaining the uniformity of the heating value of the gas. New furnace designs are discussed, and the importance of some knowledge of the flow characteristics of metals to the forger and die designer is emphasised.

Hard Spots on Nickel Steel Forgings. (Drop Forger, 1937, vol. 17, Nov., pp. 186–199). A discussion in detail from the practical and theoretical standpoints on the occurrence and causes of hard spots in forgings of 3 and 5% nickel steels.

Time Standards for the Drop Forge Die Shop. C. N. Harwood. (Heat Treating and Forging, 1937, vol. 23, Nov., pp. 549–555). The author presents a description and analysis of time studies made in the die-making department of the Interstate Drop Forge Company of Milwaukee. The application of the results of such studies is briefly indicated. Tabular and graphical data are presented.

Some Characteristics of Cold-Heading Wire. A. M. Reeder. (Wire and Wire Products, 1937, vol. 12, Nov., pp. 715–720, 739). The author considers the analyses of carbon steels for cold-heading purposes; these range in carbon content from 0·05 to 0·40%. Cold-heading properties are discussed in relation to steelmaking practice and to ingot segregation. The importance of keeping down surface decarburisation to a minimum and the use of various coatings to facilitate extrusion heading are dealt with.

Lubrication in Bar and Tube Drawing. R. Saxton. (Wire Industry, 1937, vol. 4, Nov., p. 584). After briefly discussing the purpose of lubrication in and the requirements of lubricants for bar and tube drawing, the author deals with grease and liquid lubricants, colloidal graphite, and the use of lead-tin alloy as a lubricant for stainless steel together with lubricants for mild-steel tube drawing.

Wire and Wire-Drawing Lubricants. R. C. Williams. (Wire and Wire Products, 1937, vol. 12, Dec., pp. 757–758, 790). After a preliminary discussion on the mechanism of the action of lubricants in wire drawing, the author describes the results of experiments to determine the efficacy of lubricant coatings produced from wet drawing solutions by electrodeposition. The apparatus employed and the conditions of deposition are discussed in detail. Whether or not superior lubrication is obtained is shown to depend largely on the physical nature of the deposited film which may be produced on both ferrous and non-ferrous metals. The current densities employed in practice may vary from 0·003 to 0·16 amp. per sq. in., and the duration of the period of deposition may be as short as 0·1 sec.; it is possible that the process might be employed on continuous rod-reducing machines.

Scaling of Wire Rod and its Influence on Subsequent Treatment. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 191–199). A translation into English of a paper by W. Asbeck which appeared originally in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 12, pp. 161–185. (*See* p. 62 A).

ROLLING-MILL PRACTICE

(Continued from pp. 126 A–128 A)

Lubrication of Morgoil Roll-Neck Bearings. H. H. Wood. (Iron and Steel Engineer, 1937, vol. 14, Nov., pp. 36–40). The author describes the construction and operating characteristics of the Morgoil roll-neck bearing, which is of the totally enclosed oil-film type, the inner and outer races being separated by an unbroken film of lubricant. Suitable lubricants, methods of lubrication and circulating systems are also dealt with.

Lubrication of Timken Roll-Neck Bearings. O. L. Maag. (National Lubricating Grease Institute, Chicago: Iron Age, 1937, vol. 140, Dec. 2, pp. 47–48). The requirements of greases for roll-neck lubrication are briefly discussed, with special reference to the formation of oil-water emulsions and their effects. A proprietary brand of lubricant is referred to as proving satisfactory for heavy-duty service in steel-mill bearings; lime-lead-soap-sulphur, lime-soap-sulphonated base, lead-soap-sulphur-chlorinated base, and plain chlorinated or phosphorus-treated compound base greases are referred to. The choice of suitable lubricants for different circumstances is discussed.

Lubrication of Pinions and Roll-Neck Bearings in Modern Steel Plants. J. F. Pelly. (Iron Age, 1937, vol. 140, Dec. 16, pp. 40–47; Dec. 23, pp. 34–39). The author discusses factors affecting problems of lubrication in connection with pinions and roll-neck bearings. Conditions limiting the life of pinions are analysed and cast and forged steel units are compared. Tabular data are presented regarding operating conditions and outputs in relation to pinion life. Comparisons are made between various lubricants and lubricating systems. In the second part of the article, devoted mainly to roll-neck bearings, data are presented on fabric bearings as applied to various types of mill.

Special Stand for a 925-mm. Two-High Reversing Mill. F. Münker. (Stahl und Eisen, 1937, vol. 57, Dec. 30, pp. 1447–1449). The conversion of a two-high reversing mill employed for rolling heavy sections, rails and similar products to a mill capable of rolling girders from 14 cm. high and 14 cm. wide to 75 cm. high by 30 cm. wide and others of special light construction with straight and inclined flanges is described. Special reference is made to the provision of vertical rolls and to the roll-neck bearings and lubrication. Details are also presented of drives and controls.

Drives and Control for a Modern Rod Mill. R. H. Wright and B. J. Auburn. (Blast Furnace and Steel Plant, 1937, vol. 25, Oct., pp. 1101–1102: Wire and Wire Products, 1937, vol. 12, Dec.,

pp. 759–761). The drives and controls on the Joliet rod mill of the American Steel and Wire Co. are described. (*See* p. 127 A).

Jones and Laughlin's New Strip Mill. (Iron Age, 1937, vol. 140, Dec. 16, pp. 48–55): **Continuous 96-in. Mill Now in Full Operation.** (Steel, 1937, vol. 101, Dec. 20, pp. 44–49, 66). An account is presented of the plant and plant layout of the new 96-in. continuous hot strip, sheet and plate mill and the cold-rolling equipment for sheet, strip and tinplate of the Jones and Laughlin Steel Corp., Pittsburgh. Some reference is made to the power supply.

How Thin Can Strip be Rolled? J. D. Keller. (Blast Furnace and Steel Plant, 1937, vol. 25, Oct., pp. 1110–1113). The author discusses from a mathematical standpoint the minimum thickness of strip attainable in the cold strip mill. Screwing down the rolls produces a decrease in thickness up to a point after which further screwing down tends to an increase in the thickness of the strip.

Rolling Mill Machinery Manufacture. (Metallurgia, 1937, vol. 17, Nov., pp. 1–4). A description is given of developments which have taken place in the design and construction of cold-rolling mill machinery.

Comparison Between the Different Kinds of Motor Rollers in Rolling Mills. (Demag News, 1937, vol. 11, C, Sept., pp. 17–20). The characteristics of motors for driving live rolls are examined. Stress is laid on the advantages possessed by the geared roller with internal gear drive. The power requirements of the motor are discussed.

HEAT TREATMENT

(Continued from pp. 129 A–130 A)

Production Carburising Revolutionised in 30 Years. E. F. Davis. (Metal Progress, 1937, vol. 32, Oct., pp. 347–350, 366). The author outlines the development of carburising equipment, compounds, control and practice. The trend towards the increased use of gas carburising is noted and the development of current practice briefly discussed.

Clean Carburising in the Packard Plant. (Machinist, 1937, vol. 81, Dec. 18, pp. 1080–1081). An account is presented of the gas carburising plant for the case-hardening of gears installed in the Detroit Works of the Packard Motor Car Co. The furnaces are fired with natural gas and the carburising medium is natural gas diluted in special equipment with a neutral gas. Operating data and temperatures of treatment are given.

Case Hardening of 14 per cent. Chromium Steels. (Metallurgist, 1937, vol. 11, Dec., pp. 90–92). A summary is presented of the investigations of Widawski upon the carburising characteristics of two basic electric steels containing 0·12% of carbon and 13·9% of chromium and 0·45% of carbon and 13·2% of chromium respectively. (*See also* p. 66 A).

Selective Hardening With the Oxy-Acetylene Flame. R. L. Rolf. (Steel, 1937, vol. 101, Nov. 1, pp. 48–51). The author describes set-ups for and the technique of the flame hardening of difficult components. Gears, worms, special screws and nuts and forming dies are among the examples cited.

Developments in the Nitrogen Hardening of Steel. B. Jones. (Metal Treatment, 1937, Winter issue, vol. 3, pp. 165–170). The author considers the surface-hardening by nitrogen of steels other than the chromium-aluminium-molybdenum type. After a preliminary account of the mechanism of nitrogen-hardening, the free-cutting and nickel-bearing nitriding steels are dealt with and the properties of the hardened case and of the core and their special applications are discussed. The compositions of various aluminium-free nitriding steels, including those with greater amounts of chromium and molybdenum than the LK class and those containing nickel and vanadium, are next considered. Mention is also made of tantalum- and niobium-bearing steels amenable to surface-hardening with nitrogen. The nitriding of corrosion- and heat-resisting nickel-chromium steels is dealt with and the special technique required outlined; it is pointed out that the austenitic manganese steels absorb nitrogen readily and need no special pre-treatment. High-carbon high-chromium steels, in particular those containing cobalt with smaller amounts of vanadium and molybdenum, are also

nitrided for use as die tools where high core strength is required. Special reference is made to the hardening of chromium-nickel-tungsten valve steels. The metallography of the nitrided surfaces produced on the steels is discussed and the nitriding characteristics, depth and hardness of case and the relationship between the properties of the case and the application for which the steel is intended are examined in detail.

Chapmanizing. R. L. Rolf. (Steel, 1938, vol. 102, Jan. 10, pp. 48–51). A description is given of a method developed by the Chapman Valve Manufacturing Co., Indian Orchard, Massachusetts, by which it is said to be possible to nitrogen-harden low-carbon free-cutting steels. Two modifications of the process exist; in one the metal is treated with the so-called " active " nitrogen (produced by decomposing ammonia gas) under pressure, while in the other the active gas is brought into contact with the steel in a salt bath. Equipment and plant layout, the characteristics of the case and the depth of case produced after treating for various periods are discussed. Some indication is given of the mechanism of the reactions involved in the process. Graphical and tabular data are presented.

Modern Heat-Treatment Furnaces. (Metallurgia, 1937, vol. 17, Dec., pp. 35–38). An account is given of certain recent heat-treatment furnace installations. Among the furnaces described are the Wild-Barfield vertical forced-atmosphere-circulating furnace for bright tempering, the electrode salt bath for hardening high-speed steel, the heat-treatment furnaces at the Austin Motor Co., Ltd., a cyanide furnace by Kasenit Ltd., the Ajax Hultgren salt bath, the Lee Wilson type of sheet-annealing furnace and the Incandescent bogie-type furnace for the annealing of boiler drums.

Fast Metal Melting With Gas Immersion. J. B. Nealey. (Iron Age, 1937, vol. 140, Dec. 23, pp. 40–42). The principle of the gas immersion heater is described, followed by reference to its use in salt baths and lead baths for heat-treatment purposes, pickling vats and in tinning sets.

The Development of the Electric Furnace Load. R. H. Rawll. (Wild-Barfield Heat-Treatment Journal, 1937, vol. 2, Sept., pp. 73–75; Dec., pp. 91–93). The author briefly indicates the development of industrial electric heating and describes the advantages accruing to the power-supply companies and the consumers through the increased use of electric furnaces. The benefits of electric heating in specific operations are examined. Finally operating costs for certain routine processes are considered.

Heat Treatment and Metallurgical Control. O. N. Peterson. (Metal Progress, 1937, vol. 32, Oct., pp. 337–345). The author presents a general discussion on the metallurgical control exercised upon the composition and treatment of materials for automobile construction. Grain-size control, special annealing cycle for nickel-chromium steel blanks, carburising and decarburising in a gas carburiser, heat-treating for machinability, the heat treatment of

medium-manganese, carbon and spring steels and the treatment of cold-drawn rods and tubing are dealt with.

Steels for Turbine Rotor Forgings and Their Heat Treatment. N. L. Mochel. (Metals and Alloys, 1937, vol. 8, Oct., pp. 265–269). After a preliminary account of the development of the modern turbine, the author discusses turbine-rotor forgings of the one-piece design. The considerations governing the use of carbon and alloy steels are examined, and the use of nickel steel and nickel-molybdenum steel with or without chromium and/or vanadium is dealt with; the compositions and mechanical properties of suitable materials are presented in tabular form. The heat treatment of carbon steel forgings and of alloy steel forgings is considered in detail, problems in connection with the attainment of stability and relief of internal stress in the case of the latter articles being referred to in particular. Methods of testing turbine-rotor forgings are briefly noted.

Thermal Treatment of Rods and Bolts. L. S. Cooch. (Wire and Wire Products, 1937, vol. 12, Dec., pp. 763–765). The author discusses the equipment and procedure for spheroidising rods utilised for manufacturing into bolts by cold-drawing and cold-heading operations. Final heat treatment is carried out on the finished article in an electric furnace of the belt-conveyor type; particular reference is made to the device for maintaining the oil in the quenching tank in a turbulent state, and to the control of the tempering operation.

Electric Heat Hardening of Bolts. W. F. Ross. (Iron Age, 1937, vol. 140, Dec. 23, pp. 32–33). The author describes the heat-treating equipment and practice at the Cleveland Cap Screw Co., Cleveland, Ohio. The furnaces are electrically heated and are of the continuous chain-belt conveyor type supplied with controlled atmosphere; they are employed for heat-treating nuts and bolts.

Design and Operation of Equipment for the Generation of Controlled Atmospheres for Annealing-Hardening. W. O. Owen. (National Conference on Industrial Gas Sales, Chicago, 1937: Industrial Heating, 1937, vol. 4, July, pp. 558–560; Dec., pp. 1074–1076: Heat Treating and Forging, 1937, vol. 23, July, pp. 353–354). The author briefly outlines the development of controlled-atmosphere generation, and then examines in greater detail various modern methods of obtaining the required results. Diffusion flame burners, carbon diffusion burners, combined clear-flame and smoke burners are dealt with, together with hydrogen, dissociated ammonia, and conditioned gas atmospheres. Alloy muffles and radiant gas-tube heaters are compared. The function of controlled atmospheres, gas generating equipment, the use of controlled atmospheres in malleablising furnaces and factors influencing the choice of atmosphere are finally discussed.

Preparation of Furnace Gases for Non-Oxidising Atmospheres. E. E. Thum. (Metal Progress, 1937, vol. 32, Oct., pp. 377–382).

The author discusses the part played by oxygen in reactions occurring between steel and air or furnace or combustion gases. The elimination of oxygen is shown to be essential if reactions between the steel and the atmosphere to which it is exposed at high temperature are to be avoided. The use of cracked ammonia, processed natural gas (in which, by controlled pre-combustion, the hydrogen is reduced to about 14%, and oxygen and oxides of carbon to traces by means of special absorption reagents), partially burnt town-gas or producer-gas, butane and propane is considered. A gas so burnt as to contain a carbon-monoxide/carbon-dioxide ratio of 3 : 2 is satisfactory for the annealing of sheet steel if it is freed from moisture before use. Gas-steel equilibria are discussed in relation to temperature. The availability of gas-processing units for converting fuel gas to atmospheres suitable for sheet-steel annealing is noted.

Bright Annealing of Seamless Steel Aircraft Tubing. H. R. Lewis. (Metals and Alloys, 1937, vol. 8, Dec., pp. 331–334). An account is presented of the continuous controlled-atmosphere annealing furnace for seamless steel aircraft tubing (0·25–0·35% of carbon) recently installed by the Ohio Seamless Tube Co., Shelby, Ohio. The furnace is of the gas-fired radiant tube type; the heating chamber measures 3 ft. 6 in. by 17 ft., and the overall length from charge table to discharge table is about 150 ft. A brief account is given of the manufacture of the protective gas, which is produced in a separate unit by the controlled combustion of air and gas. Some indication is given of the quality of the work produced by the furnace.

The Lavite Process of Annealing Wire. (Wire Industry, 1937, vol. 4, Oct., pp. 523–524). An account is given of the Lavite annealing process for wire. It consists of a direct (electrically) heated salt bath of special design. The construction and control equipment of the plant are described.

Electrically-Heated Close-Annealing Furnace for Sheet. G. Kuznia. (Stahl und Eisen, 1937, vol. 57, Dec. 16, pp. 1408–1409). The construction and operation of an electrically heated close-annealing furnace for sheet steel are described. Operating costs, times and efficiency are compared with those of coal- and gas-heated annealing furnaces. It is concluded that, whilst the data obtained do not necessarily demonstrate the economic superiority of the electric furnace, such a furnace is no more expensive to operate than furnaces fired by other methods. Possible avenues of economy are suggested.

A Modern Annealing Plant for a Continuous Sheet Mill. R. J. Cowan. (Iron and Steel Engineer, 1937, vol. 14, Dec., pp. 65–69). After a brief preliminary discussion on the theoretical aspects of annealing, the author describes in detail the equipment for annealing sheets recently installed by the Surface Combustion Corp. at the Lackawanna plant of the Bethlehem Steel Co. The construction of the furnaces is discussed with particular reference to the function of the radiant-tube heating units. In addition, the use and production

of protective atmospheres are considered and the advantages of radiant-tube heating examined more closely.

Electric Direct-Resistance Patenting and Tempering of Spring Wire. Part I. O. C. Trautman. (Wire and Wire Products, 1937, vol. 12, Nov., pp. 711–714). The equipment for patenting wire by a direct electric-resistance method is described; the apparatus is so designed that all operations such as pickling, coating and baking are continuous, and the quenching temperature is automatically controlled by means of a photo-electric cell unit. The use of special atmospheres is claimed not to be essential with this equipment. Operating costs, effects of grain structure, surface decarburisation, uniformity of heating and the physical properties of the product are considered at length.

Electric Direct-Resistance Patenting and Tempering of Spring Wire. Part II. O. C. Trautman. (Wire and Wire Products, 1937, vol. 12, Dec., pp. 767–771). The installation of equipment for the direct-resistance patenting of wire at the works of the Cleveland Wire Spring Co. is noted. The particular value of the method for the annealing of austenitic steel wires is discussed, and the inadequacy of prevalent oil-tempering methods is compared with the excellent results obtained by direct-resistance tempering; the conditions of quenching to obtain optimum results by this latter method differ from those suitable for material heated in the conventional manner, and a special low-melting-point alloy in conjunction with oil is employed as a quenching medium; the theoretical aspects of the process are considered. The mechanical and physical properties of the electrically treated wire are shown to be superior to those of oil-tempered wire. (*See* previous abstract).

Bright-Annealing. (Midland Metallurgical Societies, Dec. 2, 1937: Iron and Coal Trades Review, 1937, vol. 135, Dec. 10, pp. 973–974). Among the papers contributed to a general discussion on bright-annealing held at a meeting of the Midland Metallurgical Societies in Birmingham, one, by E. C. Rollason, dealt with gas-metal reactions involved in problems connected with the annealing of metals. A. G. Robiette considered the nature, production and use of various controlled atmospheres; J. L. Pearson discussed the use of a nitrogen-hydrogen atmosphere for annealing. Other papers dealt with vacuum annealing, the effect of surface contamination on the efficacy of bright-annealing, and with the application of the process.

Recuperative Bright Annealing. J. Macdonald and H. G. Lindner. (Wild-Barfield Heat-Treatment Journal, 1937, vol. 2, Dec., pp. 94–97, 90). An account is given of the construction and operation of the Gibbons-Wild-Barfield system of heat-recuperation as applied to a bell-type annealing furnace, which involves the forced circulation of a protective atmosphere inside the retorts, so that the medium of heat transfer is the protective gas itself which comes into actual contact with the work. Careful control of fan design and of the location of ducts is said to give highly efficient heat transference.

Notes on Hardening. J. C. Chaston. (Wild-Barfield Heat-Treatment Journal, 1937, vol. 2, Dec., pp. 86–90). The author considers in detail the essentials of a correct hardening technique for steel. Particular attention is paid to the means of preventing distortion during both heating and soaking-out in the subsequent quenching operation.

The Electrode Salt Bath for Hardening High-Speed Steel. A. Hultgren. (Transactions of the American Society for Metals, 1937, vol. 25, Dec., pp. 1166–1176). The author describes the factors associated with the electrically-heated salt bath which cause decarburisation, oxidation and burning of high-speed tool steel. Data are presented on the use of silica in the salt bath to prevent decarburisation, and differences obtained in the case of molybdenum-tungsten steels on heating in barium chloride baths with and without silica additions are discussed at length. Immersed electrode furnaces are best for hardening high-speed steels, but, if incorrectly designed, they may result in the passage of current through the steel, resulting in local overheating and partial fusion. The use of closely spaced pairs of electrodes overcomes the danger of local overheating.

Differential Hardening by Induction. (Iron and Steel Industry, 1937, vol. 11, Dec., p. 116). The "Tocco" surface hardening process developed by the Ohio Crankshaft Co. is described. The component to be hardened is heated by high-frequency induction by means of special equipment only at the point required, the remainder of the work undergoing little rise in temperature. Quenching is rapid, thus scaling is reduced to a minimum. Equipment with automatic control has been devised. The composition, heat treatment and structure of steels suitable for treatment are considered.

Electric Muffle Furnaces for Hardening Steel. K. H. Twele. (Engineering Progress, 1937, vol. 18, Sept., pp. 203–205). The author discusses the advantages of electrically-heated muffle furnaces for hardening tool and high-speed steels. The design and operation of small muffle furnaces are considered, together with the construction of chamber furnaces for annealing and case-hardening larger components. Silit muffles, double-chamber muffles, tempering muffles and the economic efficiency of electric muffle furnaces generally are dealt with.

Accurate Determination of Slow Changes in Length. H. Swedenborg. (Jernkontorets Annaler, 1937, vol. 121, No. 10, pp. 633–636). A new method is described for measuring the small dimensional changes sometimes observed in hardened steels. The specimen constitutes one plate in a condenser inserted in one of two dynatron high-frequency circuits, a specially designed micro-condenser being inserted in the other; each circuit is tuned to a frequency of about one megacycle, a beat frequency of about 50 cycles being chosen and measured with a reed frequency meter after rectification and amplification in the low-frequency stage. Changes in length of the order of 5×10^{-6} mm. may be detected.

WELDING AND CUTTING

(Continued from p. 131 A)

The Status of Welding in 1937. L. C. Bibber and E. Gammeter. (Metal Progress, 1937, vol. 32, Oct., pp. 551–553, 556–558, 560). After a brief preliminary note on the increased applications of welding in 1937, the authors pass on to a consideration of developments in welding technique and processes which are classed as pressure or non-pressure types. Bare metal arc and shielded metal and carbon arc welds are considered, and reference is made to the recently introduced conductive-melt process and its special applications. Gas welding, flame-hardening and hard-surfacing are dealt with and thermit welding is discussed at some length. Under the heading of pressure welds reference is made *inter alia* to interrupted spot welding, which is claimed to be suitable for the spot welding of materials up to 1 in. thick. Finally the relationship between the cost and design of welded structures is examined.

The Development of Arc Welding. (Revue de la Soudure Autogène, 1937, vol. 29, Dec., p. 270). A brief résumé is presented of the equipment and materials employed for arc welding, the scope of the process, and the qualifications required of operators.

Growth and Spread of Arc Welding in Canada. A. S. Wall. (Welding Journal, 1937, vol. 16, Nov., pp. 5–11). The author discusses the growing use of arc welding in Canadian engineering practice. Brief notes are included on electrodes, welding technique, stress relief in welded pressure vessels by annealing, X-ray examination, and the training of operators. A detailed analysis of various types of joints is presented.

Resistance Welding Widened by Tube Control. E. H. Vedder and J. W. Dawson. (Iron Age, 1937, vol. 140, Nov. 4, pp. 28–33, 81–82; Nov. 18, pp. 44–49). The authors review the processes of spot welding, butt welding, projection welding and seam welding and consider the factors influencing the quality and cost of the work. Weld timing is dealt particularly in regard to the use of electron tube timers. A number of applications of ignitron-tube equipment are discussed with special reference to quality and cost of the work. Apart from accurate timing, heat and sequence control is also practicable with electronic tube control.

Fusion Welded Pressure Vessels. S. J. Thompson. (Manchester District Association of Gas Engineers, Oct. 15, 1937: Welding Industry, 1937, vol. 5, Nov., pp. 353–355). After a preliminary discussion on the development of fusion-welded pressure vessels in America, the author considers methods of testing the quality of the welds, the material from which the vessels are fabricated, the welding technique employed and the process of routine testing.

Welding of Cast Iron. R. L. Rolf. (International Acetylene Association: Metal Progress, 1937, vol. 32, Dec., pp. 777–779). Reviews are presented of papers read at the Thirty-Eighth Annual Convention of the International Acetylene Association held at Birmingham, Ala., in Nov., 1937. The welding of cast-iron pipes is dealt with, together with the testing of the welds and corrosion phenomena. In a discussion on flame machining and hardening, the deseaming of steel billets by means of the cutting flame and the effects of gas cutting on the physical properties of certain steels are dealt with.

Oxy-Acetylene Welding in Repair Work. R. Salelles. (Revue de la Soudure Autogène, 1937, vol. 29, Dec., pp. 273–275). The author deals with the technique of repairing broken castings by means of oxy-acetylene welding. The application of the process to cast iron and the precautions to be observed with this material are among the subjects discussed.

Researches on the Influence of the Melting Rate of Steel Electrodes on the Quality of Welded Joints. H. Specht. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, Dec., pp. 252–262). By means of experiments it was determined whether and to what extent the welding properties of bare steel electrodes employed for the welding of structural steels St 37 and St 52 were altered by increasing the melting rate. It was demonstrated that, with the electrodes used, losses due to spluttering were increased, the specific gravity of the welded material was decreased, the formation of the bead was adversely affected and penetration decreased. The mechanical properties of V welds were also affected adversely under these conditions, but no effect on the composition of the weld-metal could be determined.

Shrinkage Stresses in Welding. A Review of the Literature to January 1, 1937. W. Spraragen and G. E. Claussen. (Welding Journal, 1937, vol. 16, Nov., Supplement, pp. 2–62). In the fusion welding of low-carbon steel 0·5 in. or more in thickness, without preheating, subsequent annealing or peening, residual stresses which approach the yield point of the material are introduced perpendicular to the weld and at distances 2 in. and less from it. The stresses parallel to the weld are even greater, as complex strains apparently raise the yield point by 30% or more. The interpretation of strain-gauge measurements in terms of residual stress requires caution; such measurements often indicate permanent deformation which has resulted in the reduction of residual stresses to at least the yield point, and microscopic cracking may have occurred. The so-called "direct" method of determining residual stresses—the determination of variations in the distance between gauge points on a plate—is considered highly unsatisfactory. Similar precautions are to be observed in interpreting the results obtained by methods purporting to measure "relief of stress" after welding. It cannot yet be decided whether or not residual stresses of the type

discussed are harmful or what becomes of them when the component is put into service. Residual stresses in various types of joints produced by oxy-acetylene and arc welding are considered in detail and the theoretical aspects involved are dealt with.

Internal Stresses in Welds—Their Cause and Effect. A. B. Kinzel. (Metals and Alloys, 1937, vol. 8, Oct., pp. 277–280). Internal stresses are produced in unrestrained welded structures owing to differential volume changes produced by temperature gradients, the intensity of the stress produced being largely determined by the steepness of the temperature gradient involved. Internal stresses at right angles to the applied load and of sufficient magnitude inhibit plastic deformation of the material; the occurrence, significance and means of relieving such stresses are discussed. In general the effects of internal stresses may or may not be serious, according to their magnitude and direction; they may readily be eliminated if this is economically warranted.

Nitrogen Needles in Atomic Hydrogen Welds. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report, 1936, p. 85). The results of experiments to determine the occurrence of nitride needles in atomic hydrogen welds are presented, the welds being hand-made with both cracked ammonia and hydrogen. The conditions governing the presence of nitride needles are briefly discussed.

Welding Economies and Application. E. W. P. Smith. (Iron and Steel Engineer, 1937, vol. 14, Sept., pp. 58–60). The author examines the mechanical stresses to which welds may be subjected, and their influence on the design of fabricated structures is discussed. An analysis is then made of the cost of arc-welding operations.

Concerning Unsuccessful Welds. H. Gerbeaux. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Aug.–Oct., pp. 2849–2858). The author discusses at length failures in welds due to faulty preparation of the materials to be welded or to the use of an unsatisfactory welding technique. The article deals chiefly with mechanical stresses arising in the welded material as a result of thermal effects and with means of avoiding such causes of failure by the correct designing of the joint.

The Repair of Damaged Iron Castings. C. H. S. Tupholme. (Welding Industry, 1937, vol. 5, Oct., pp. 310–312). After discussing the metallography of grey, white and malleable cast irons in relation to the oxy-acetylene welding process, the author passes on to a consideration of the technique of bronze-welding and its applications and the fusion-welding technique. The selection of a suitable welding process is discussed in relation to specific components.

PROPERTIES AND TESTS

(Continued from pp. 138 A–155 A)

The Importance of Controlling Material Cost and Quality. F. Tanzen. (Metallwirtschaft, 1937, vol. 16, Nov. 26, pp. 1253–1254). The author discusses the organisation of a material-inspection system and department, and of departments for testing finished products purchased from outside concerns and for maintaining supervision of the accuracy of gauges and precision measuring instruments in the steel- and metal-working industries. The importance of such control is stressed.

Vital Problems Concerning the Testing of Metals. E. Siebel. (Metallwirtschaft, 1937, vol. 16, Nov. 26, pp. 1229–1231). The author discusses the aims and purposes of the mechanical testing of metals, the choice, standardisation and limitations of testing methods, certain problems still to be clarified in connection with the reactions of metals to dynamic stress, and machining and wear tests.

Mechanical Tests and their Engineering Significance. J. C. Chaston. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 159–164). The author discusses mechanical tests and the relationship between data obtained by such tests and designers' calculations. The interpretation of test results in terms of service performance, and the fundamental principles governing the mechanical behaviour of metals and the relationship between these and test results are considered at length.

Selection of the Proper Steel. A. E. Focke. (Heat Treating and Forging, 1937, vol. 23, Sept., pp. 461–464, 467). The author discusses the method of selecting steels for particular purposes on the basis of S.A.E. Specifications.

Static and Dynamic Tensile Tests on Austenitic Manganese Steels. H. Krainer. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 279–282). The author describes experiments on and discusses in detail the static and dynamic tensile properties of a series of austenitic manganese steels containing between 14 and 20% of manganese and between 0·6 and 1·4% of carbon, with and without various additions of silicon, nickel, chromium, copper, tungsten, molybdenum, vanadium, tantalum, titanium and zirconium. Results are presented in graphical and tabular form, and the true strength of rupture, energy of deformation and specific work-hardening are discussed.

The Yield Point of Mild Steel under Special Experimental Conditions. A. Krisch. (Metallwirtschaft, 1937, vol. 16, Dec. 17, pp. 1321–1324). The results of tensile tests carried out on mild steel

in the region of the yield point with direct-loading equipment and in a highly elastic testing machine are described; the apparatus was in both cases fitted with a self-recording oscillograph actuated by a condenser which served to determine the load, whilst the elongation was recorded on the same graph by a photo-electrically operated device. The current stress-strain diagram for mild steel in the neighbourhood of the yield point was confirmed.

Behaviour of Stationary Wire Ropes in Tension and Bending. D. M. Stewart. (Transactions of the American Society of Civil Engineers, 1937, vol. 102, pp. 606–650). The results are described of an investigation of the behaviour of wire ropes in tension and bending which was undertaken to determine their strengths and the stresses produced under load. The values obtained were compared to those given by several formulæ in common use. Nine tension and thirty-six bending specimens were tested over sheaves of four diameters. The ropes selected were 1 in. in dia., with hemp centres, and the tests included studies of regular and Lang lay ropes of 6×7 and 6×19 construction and of preformed and non-preformed types in two different grades of steel. Important results were obtained from curves for the loss of strength in bending and for the variation in modulus of elasticity of the rope under pre-stressing. A comparative summary is given of stresses and strengths as observed and as computed by several formulæ.

On the Compression of Mild Steel. M. Nakahara and C. Han. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, Aug., pp. 220–223). The authors examine mathematically the effect of variations in the ratio of the dimensions of mild-steel test-pieces on results obtained in compression tests.

On the Conversion of Lattice Constants into Stresses when Measuring Stresses by Means of X-Rays. H. Möller and G. Strunk. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 22, pp. 305–315). The dependence of the value of the elastic modulus deduced from X-ray measurements on the direction of irradiation as proposed in the hypothesis of Möller and Barbers was calculated for a number of different directions. The relationship between lattice constants and stresses was deduced according to the new assumptions made in the paper. To prove these hypotheses, two bend tests and a tensile test were conducted. A comparison between the observed and calculated elastic curves showed better agreement when anisotropy was taken into account according to the first hypothesis; the crystal conglomerate, therefore, does not behave like an isotropic medium. In the determination of individual stresses according to the method of Gisen, Glocker and Osswald with radiographs taken at right angles and at less than 45° to the surface, the influence of anisotropy is of no importance.

Measurement of Internal Stress by X-Rays. T. Nishihara and K. Kojima. (Transactions of the Society of Mechanical Engineers,

Japan, 1937, vol. 3, Aug., pp. 203–207). The authors note the limitations of the photo-elastic and direct methods of determining local internal stress and consider the use of an X-ray technique, which is briefly described. Graphical data are presented.

Explanation of the Cause of Failures during the Working of Iron and Steel. A. Pomp. (Metallwirtschaft, 1937, vol. 16, Nov. 19, pp. 1205–1210). The author considers failures occurring during processes involving the mechanical working of steel in the light of structural defects, such as coarseness of grain, hard spots and modification of a local or general nature due to welding, galvanising and allied processes and to hydrogen absorption.

Deterioration of Steel Under Service Conditions. R. A. MacGregor. (Transactions of the Mining, Geological and Metallurgical Institute of India, 1937, vol. 33, Dec., pp. 207–219). The author presents a general discussion on failure in service by fatigue as exemplified by numerous cases drawn *inter alia* from marine-engineering practice in connection with internal-combustion engines.

Fatigue Testing of Steel Wires under Varying Tensile Stress. I. Influence of the Method of Manufacturing the Wire on the Strength under Fluctuating Tensile Stress. A. Pomp and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 17, pp. 237–246). Two steel wires of the same composition, one in the drawn, patented condition, the other in the tempered state, were subjected to fatigue stressing under varying tensile loads in air and under the water spray. The composition of the steel, the construction and mode of operation of the testing machine and the method of calibrating it are described, together with the conditions observed during the tests and the interpretation of the results. In tests on the wire in the as-delivered condition no effects due to manufacturing method could be determined; in addition, the gradients of the varying stresses used confirmed that the alternating stress was independent of the mean stress. The decrease in strength under fluctuating tensile stress with simultaneous corrosion was found to be approximately 45·5% for both types of wire. When the wires were deformed by bending prior to testing, the strength under fluctuating stress decreased and the corrosion-fatigue strength of wires so treated was equal to about a third of the strength under fluctuating stress of wires similarly treated and tested in air. Pre-deformation of the wires in torsion exerted a more unfavourable effect on the fatigue strength of the tempered wire than on that of the drawn, patented wire. The extent of the additional deformation by torsional stress appeared also to exert an effect on the strength under fluctuating stress.

New Knowledge on Fatigue Effects During Tension-Compression Stressing. G. Welter. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 294–305). From the results of a series of experiments it is concluded that the surface condition of a test-piece stressed in alternating tension and compression is of less

importance than in the case of a specimen subjected to alternating bending, that four different stages occur in the heat evolution accompanying the fatigue stressing of mild steel, that early in the process of fatigue stressing—before heat evolution begins—mild steel undergoes marked alterations in mechanical properties, that surface alterations on the stressed material are not readily visible either immediately before or after failure by fatigue, that mild steel on subjection to alternating tensile-compressive stresses exhibits temperature rises which bear some relationship to the specific loading (such temperature rises become very small or vanish in the neighbourhood of the fatigue limit), that on well-polished specimens subjected to alternating stresses for various periods faint surface markings may be detected under high magnification during the initial half of the testing period, and that on conical specimens subjected for some time to tensile-compressive stresses zones can be detected microscopically which may be differentiated into areas loaded respectively above and below the fatigue limit.

Endurance Tests on Structural Steels. A. S. Joukoff. (Ossature Métallique, 1937, vol. 6, Dec., pp. 585–590). The author discusses the theory and practice of endurance strength determinations and considers in detail the application of the results obtained to structural mild steels in the shape of flat bars in the plain, drilled and riveted forms.

Behaviour of Welded and Bolted Rigid Joints under Static and Alternating Stress. F. Körber and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 19, pp. 273–287). The authors describe a series of tests on welded and bolted joints in girders under static and alternating stress. The testing apparatus and measuring instruments employed are described and results are presented in graphical and tabular form.

The Effects of Variation in Diamond Indenters used in the Vickers Hardness-Testing Machine. F. B. Fuller. (Transactions of the American Society for Metals, 1937, vol. 25, Dec., pp. 1198–1206). The Vickers hardness testing machine developed in England for the testing of thin sheet has received considerable attention in America for the study of surface-hardened materials, welded joints and thin sheet. Comparisons of data from different sources may be affected by variations in the diamond indenting tools. Hardness data are discussed which were obtained with a Vickers hardness testing machine using three standard diamonds under comparable testing conditions and on uniformly hardened alloy steel blocks over a wide range of hardness. It is indicated that unless the accuracy and finish of the indenting pyramid are satisfactorily controlled, discrepancies in hardness values and irregular impressions may be expected.

Aspects of Metallic Wear. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 177–180, 185). The nature of "wear" is defined

and wear tests are discussed. The process of lubrication is considered and the mechanics of wear and its counteraction by oils and greases are dealt with, together with various physical, mechanical and chemical factors affecting the wear process. In conclusion the wear of cylinders, oxidation wear and the effect of debris upon the wearing characteristics of dry and lubricated surfaces are dealt with.

Hardness, Machinability, and Resistance to Abrasion. G. Schlesinger. (Journal of the Institution of Production Engineers, 1937, vol. 16, Dec., pp. 656–685). The author describes the basic processes involved in turning operations (and allied mechanical-working processes) on steel. The testing of turning tools of various materials is described and graphical data are presented respecting the life obtained under various conditions. Life curves are also given for high-speed steel drills under various conditions of operation. Abrasion in the working parts of machines is discussed, and the results of tests carried out with the Spindel M.A.N. machine are described. It was found that there is no simple relationship between the wear of steel, the degree of pressure, the speed of motion in the case of rolling or sliding parts (in the absence of abrasives) and the hardness of the body causing the wear. The influence of hardness on machinability and resistance to abrasion is considered in detail. The behaviour of cast iron is considered under a special heading. Data in tabular and graphical form and a bibliography are presented.

Comparative Tests on Grease-Lubricated Synthetic and Metal Bearings for Service in Intermittent Crane Operation. H. Ernst. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1937, vol. 5, Dec., pp. 243–251). The results are described of experiments on the running properties under intermittent and alternately reversed rotation of red-brass, synthetic-resin and cast-iron bearing linings for use in cranes. The cast irons tested, the compositions and structures of which are described, proved inferior under the conditions of the experiment to both red brass and synthetic resin.

Metal Sprayed Surfaces in Relation to Lubrication. H. Shaw. (Association of Metal Sprayers, 1937 : Metallurgia, 1937, vol. 17, Nov., p. 31). **Metal Sprayed Surfaces for Bearings.** H. Shaw. (Metal Industry, 1937, vol. 51, Oct. 29, pp. 427–430). The author describes the results of investigations on the frictional and load-carrying properties of metal-sprayed steel shafts running in white-metal bearings. The instruments employed—the " Frictiograph " and the " Contorograph "—are described and their mode of operation is explained. Phenomena of seizure and surface etching are discussed together with data regarding the strength of sprayed metal coatings.

The Effect of Change of Temperature on the Strength of Permanent Magnets, With Special Reference to Modern Magnet Steels. A. C. Whiffin. (Journal of the Institution of Electrical Engineers, 1937, vol. 81, Dec., pp. 727–740). From a survey of the literature it is seen that the magnetic strength of a magnet may be rendered

steady by mechanical shocks or by cyclic heating. At each temperature it has a definite strength, the strength/temperature coefficient being, in general, negative. The coefficient depends on the linear dimensions of the magnet, being reduced by increasing the length/breadth ratio and by suitable heat treatment. In the case of carbon steels, increase in the carbon content reduces the coefficient. An account is given of a rotating search coil and ballistic galvanometer employed for testing cobalt steel, aluminium-nickel and aluminium-cobalt-nickel alloy magnets at temperatures from −60° C. to 100° C. When the magnets had attained the reversible state it was found that H_τ was related to the temperature τ (° C.) as follows :

$$H_\tau = H_0(1 + a\tau + b\tau^2)$$

The negative constants a and b are determined for each magnet. The total loss of strength up to the steady state was also determined. In the cobalt steels, a decreased with increase of cobalt. In the 15% cobalt steels and the aluminium-nickel alloys, both with and without cobalt, the value of a and the loss of strength were affected by the temperature at which magnetisation was performed. The other cobalt steels tested were magnetised at ordinary temperatures.

Magnetic Properties of Nickel-Copper-Iron Alloys. (Metallurgist, 1937, vol. 11, Dec., pp. 88–90). A discussion is presented, with graphical data, upon the influence of copper additions upon the magnetic properties of iron and the iron-nickel alloys.

Permanent Magnet Material is Finding Widening Applications. (Steel, 1937, vol. 101, Dec. 27, pp. 38–40, 60). An account is given of the manufacture of " Alnico " magnet alloy by the Continental Motors Corp., Detroit. The alloy contains 63% of iron, 12% of aluminium, 20% of nickel and 5% of cobalt, and is melted in a high-frequency induction furnace; it is employed in the cast state. Brief references are made to its magnetic characteristics, which are compared with those of other permanent magnet steels, and some current applications are noted. Graphical data are included.

The Problem of the Temperature Coefficient of Tensile Creep Rate. J. J. Kanter. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 863; Metals Technology, 1937, vol. 4, Dec., No. 8). The interrelation of stress, temperature and tensile creep rates of metals has been intensively studied. It has been suggested that at small stresses the secondary or constant creep rates obey a simple law of viscosity and that departures from this law at higher stresses may be expressed mathematically as reversibly altered viscosity or " flowability "; a temperature change results in reversibly altered viscosity. The index to the alteration of viscosity enables the value of the energy of secondary creep to be derived, the figure obtained possessing the magnitude of the free energy of vaporised metal. It is also suggested that the application of stress alters the energy of secondary creep, and strain energy is said to be a minor factor only in the energy system

characteristic of secondary creep; the deformation mechanism associated with this energy implies a type of solid self-diffusion process. Evidence indicates that at temperatures above the point of recrystallisation creep strain occurs by preferential diffusion at grain boundaries and at points of crystal defects. A self-diffusion theory of secondary creep is proposed embracing the principles of the Dushman-Langmuir theory of solid diffusion. An equation is suggested whereby the rate of tensile creep may be related directly to the physical and structural character of the solid metal.

Low-Temperature Impact Properties of Molybdenum Steel. (Moly. Matrix, vol. 4, No. 10: Alloy Metals Review, 1937, vol. 1, Dec., pp. 62–64). A range of seven steels containing between 0·15 and 0·45% of carbon, 0·15 to 0·47% of molybdenum and with and without additions of chromium from 0·5 to 1·1% and nickel from 1·65 to 3·75% was subjected to impact tests at temperatures down to −190° C. The grain-size characteristics and heat treatments given to the steels prior to testing are presented in tabular form. The hardness of the steels appeared to bear little relationship to the impact resistance, but whilst inherent grain size had no effect, that resulting from heat treatment did; a small crystal size gave good impact values at low temperature.

The Hydrogen Brittleness of Carbon Steels in Relationship to the Amount of Hydrogen Absorbed. P. Bardenheuer and H. Ploum. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 21, pp. 299–303). The authors describe the results of further investigations on the hydrogen embrittlement of steels. (*See* Journ. I. and S.I., 1934, No. II., p. 679 A). The process of hydrogen absorption by steel wires of various carbon contents during electrolysis and during heating in an atmosphere of hydrogen under various conditions was examined. The brittleness resulting from these treatments was determined by bend tests. The fracture of electrolytically-treated wire exhibited a circular " flaked " zone the width of which depended on the duration of the treatment and the degree of hydrogen absorption. On storing the material, the mechanical properties, which had been modified by the hydrogen, were partially restored as the gas was released from the metal, but no return to the original condition was observed; after removal of the hydrogen its destructive action was still manifested to a degree depending on the amount originally absorbed.

Permeability of the Atomic Lattices of Metals to Hydrogen. M. Widemann. (Metallwirtschaft, 1937, vol. 16, Dec. 24, pp. 1367–1369). The author demonstrates that the views of certain investigators, who hold that the metallic lattice is permeable to hydrogen, are theoretically unsound. As channels of diffusion only grain boundaries, flaws, fissures between lattices and allied paths are to be considered. As a probable explanation of the varying behaviour of metals regarding permeability to hydrogen

at elevated temperatures and in electrolytes, the hydrogen-atom concentration and its dependence on temperature and the atomic characteristics of the metal in contact with the gas, are examined.

The Diffusion of Hydrogen through Metals. W. Baukloh and W. Wenzel. (Dissertation, Technische Hochschule Berlin, 1937 : Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 273–278). The significance of the surface condition and structure of metals in relation to hydrogen adsorption is discussed. A theory is developed regarding hydrogen adsorption during electrolytic pickling which seeks to explain the influence of arsenic and sulphur and of mechanically activated metal surfaces upon this adsorption. Experiments are described on the influence of surface conditions on permeability on heating in hydrogen. Experiments on the hydrogen permeability of iron-manganese-carbon alloys and on a hardened steel test-piece demonstrate the discontinuity in permeability at the $\alpha \rightleftharpoons \gamma$ transformation and its diminution with increasing carbon contents.

Influence of Boron Additions up to 0·1% on the Mechanical Properties of Cast Steel Containing 0 to 5% of Nickel. G. Naton and E. Piwowarsky. (Dissertation, Technische Hochschule, Aachen, 1936 : Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 283–286). The mechanical properties of two Bessemer steels containing 0·13 and 0·24% of carbon with simple additions of 0·02 to 0·1% of boron and with additions of 1 to 5·0% of nickel and 0·02 to 0·1% of boron were investigated. Under all conditions of heat treatment the strength and hardness of all the steels increased with increasing boron contents. Boron-free steels annealed at 50°, 150° and 250° C. underwent a greater or less diminution in hardness, whilst those containing boron maintained their hardness or exhibited mild precipitation-hardening phenomena. Boron additions resulted in a refined grain size, and on annealing quenched specimens containing boron a marked refining of the martensite was observed, whilst in the boron-free steels it exhibited the initial signs of breakdown.

Modern Views of Cast Iron. A. L. Norbury. (Manchester Metallurgical Society : Foundry Trade Journal, 1937, vol. 57, Dec. 16, pp. 471–473). The author discusses the mechanism by which different microstructures may be developed in cast iron of a given analysis, and indicates the treatments by which such differences may be produced. The manner in which the mechanical and physical properties of the metal are affected is considered. The control of the graphite formation is chiefly dealt with.

The Growth of Grey Cast Iron. (Third Report). H. Sawamura. (Memoirs of the College of Engineering, Kyoto Imperial University, 1937, vol. 10, July, pp. 51–63). From the author's investigations the following conclusions are drawn : When grey cast iron in the as-cast state is maintained at a high constant temperature in air, growth occurs, but to no considerable extent. If, however, the metal is previously heated above its critical range and then treated in this

way, it undergoes pronounced growth; hence it was confirmed that the abnormal expansion at the Ar transformation is intimately connected with the phenomenon of growth. Experiments in various gases confirmed that growth is due to oxidation, which is a factor of more importance than the abnormal expansion previously mentioned. Growth occurred in carbon monoxide owing to the dissociation of the gas and the deposition of carbon in internal fissures and cavities and the sites of graphite flakes. (*See also* Journ. I. and S.I., 1937, No. II., p. 196 A).

Alloying of Malleable Iron. W. F. Chubb. (Foundry Trade Journal, 1937, vol. 57, Dec. 9, pp. 457–458; Dec. 16, pp. 465–467). The author considers in detail the effects of molybdenum on malleable cast iron and concludes that it reduces the danger of obtaining mottled iron if the composition of the iron tends to vary; it promotes the production of sounder castings; it produces a tougher malleable iron and increases the ductility of the original white iron, thereby reducing the number of white-iron castings broken in handling; heavier sections may be cast; a reduction in annealing time is sometimes permitted; losses due to cracking of white iron in the moulds are reduced; the tensile strength and ductility are increased; improvements may be effected in the presence of molybdenum by suitable heat treatments; and an appreciable refinement of grain structure is produced. Tabular and graphical data are presented in the account.

Concerning New Stainless, Acid-Resisting and Non-Scaling Steels and Their Use. H. Hougardy and G. Riedrich. (Metallwirtschaft, 1937, vol. 16, Dec. 17, pp. 1329–1342). The authors discuss in detail the compositions, properties and applications of the ferritic, martensitic and austenitic acid-resisting steels and non-scaling steels. In respect to acid-resisting steels, special attention is paid to resistance to chemical attack by various corrosive media, to workability and to weldability. Clad materials are dealt with in the final section of the article. Data are presented in tabular and graphical form.

Diversification of Stainless for Special Purposes. E. E. Thum. (Metal Progress, 1937, vol. 32, Oct., pp. 597–604, 608). Reference is made to 4–6% chromium steels for use in oil-refining plant and to the relative merits of titanium, molybdenum and niobium for preventing temper-brittleness in such materials; steels containing 9% of chromium and 1·5% of molybdenum for service at temperatures up to 1250° F. are also noted. The uses of the so-called non-hardenable chromium irons containing from 17 to 25% of chromium with additions of nitrogen to promote grain refinement or of molybdenum, aluminium or silicon to confer, in the case of the first addition, resistance to nitric acid and, in the case of the other additions, to give increased heat resistance, are considered at length; the structures and mechanical properties of these steels are briefly noted. In connection with the austenitic chromium-nickel steels the use of special additions to combat weld-decay is discussed,

including additions of silicon up to 6%. The use of steels containing 24% of chromium and 10–14% of nickel or 20–25% of chromium and 20–22% of nickel for high-temperature service is considered with special reference to the carbon contents. Pitting phenomena occasioned by sea water and brine in contact with 18/8 steel are considered at length with comments on the mechanism of the reactions involved and means of preventing their occurrence. In conclusion the tensile-strength/endurance ratio of 18/8 stainless steel is discussed and certain comparisons are made between the mechanical properties of this material and those of high-strength aluminium alloys used in aircraft construction.

Engineering Production in Stainless Steel. E. J. W. Ragsdale. (Society of Automotive Engineers, Oct. 7–9, 1937 : Iron Age, 1937, vol. 140, Dec. 23, pp. 43–45). The author discusses special problems in connection with the fabrication and assembly of airplane components in light-gauge 18/8 stainless steel. The attainment of rigidity, and riveting and welding techniques are considered in turn; particular reference is made to the suitability of small portable electric welding machines for dealing with the material.

Developments and Applications of Acid and Heat-Resisting Steels. W. H. Hatfield. (Metallurgia, 1937, vol. 17, Dec., pp. 53–55). The author reviews the growing demand for acid- and heat-resisting steels, and some applications of corrosion-resisting steels in the chemical industries are discussed. The applications of both acid- and heat-resisting steels in the engineering, aircraft and automobile industries, and miscellaneous applications are noted. Reference is made to a steel specially adapted for turbine blading.

Heat-Resistant Steels. J. Biren. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 249–270). After a preliminary discussion on the purpose of heat-resisting alloys—steels in particular—the author briefly considers the physical, chemical and mechanical conditions which such steels encounter in service. The author then considers the materials under the following heads : Steels subjected to mechanical stressing at temperatures below 600° C.; steels subjected to mechanical stressing and chemical attack at temperatures not above 600° C.; steels resistant to temperatures above 600° C. with exposure to oxidising and other corrosive gases; similar steels under like conditions subjected in addition to simultaneous mechanical stressing. Tabular data are presented regarding the compositions and physical and mechanical properties of the steels dealt with.

Chrome-Molybdenum Steels. W. F. Chubb. (Iron and Coal Trades Review, 1937, vol. 135, Dec. 24, pp. 1043–1044; Dec. 31, pp. 1086–1087). The author discusses the analyses and properties of chromium-molybdenum steels for case-hardening purposes, structural work, and for castings. Tabular data are presented regarding the mechanical properties of the steels in various conditions of heat treatment. The applications of the steels are noted and reference is

made to British and to American practice. Structural steels containing 0·25–0·35% of carbon, 0·5–0·8% of chromium and 0·15–0·25% of molybdenum are discussed. High chromium-molybdenum steels for the manufacture of components subjected to impact stresses at high temperature, and special creep-resistant chromium-molybdenum steels are also dealt with, together with high-duty steels for the oil industry. The heat treatments of the steels are discussed and tabular data presented regarding their mechanical properties.

Nickel-Molybdenum Steels. W. F. Chubb. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 173–176). The author discusses the compositions, heat treatments, mechanical properties and applications of low- and medium-carbon nickel-molybdenum steels; in particular case-hardening steels of this class are considered at length. Data are presented in tabular form.

Trends in Alloy Steels in England. J. H. G. Monypenny. (Metal Progress, 1937, vol. 32, Oct., pp. 447–454). The author presents a general discussion on trends in development of alloy steels in England in so far as bars and forgings of relatively small size are concerned. The use of case-hardening steels containing 1·0% of chromium is mentioned and reference is made to the mechanical properties of nickel, nickel-chromium and nickel-chromium-molybdenum steels for carburising purposes. The mechanical properties and applications of the lower-alloy steels are also discussed with particular reference to steels containing about 1·5% of manganese with or without 0·25–0·5% of molybdenum and sometimes with nickel or chromium up to 0·5%. Chromium-vanadium steels, low nickel-chromium steels and the air-hardening nickel-chromium steels are referred to and their mechanical properties discussed at some length.

Trends in Alloy Steels in America. E. E. Thum. (Metal Progress, 1937, vol. 32, Oct., pp. 463–466). The development of alloy steels in America is briefly discussed, and reference is made to early attempts to fix limits to their compositions and to the super-abundance of varieties at present on the market. With improved conceptions of engineering design lower-alloy steels have found increasing application. The significance of grain-size control and the presence of " incidental " alloys in nominally alloy-free open-hearth steels are considered at some length.

Modern Developments in Structural Steels. J. A. Jones. (Metallurgia, 1937, vol. 17, Dec., pp. 57–59). Recent developments in mild structural steels containing the cheaper alloying elements and which require no heat treatment to develop satisfactory mechanical properties are discussed. Steels containing up to 1·8% of manganese, low-carbon steels with 2–3% of nickel, low-carbon steels containing 1·0% of silicon or 0·5–1·5% of manganese with 0·6–1·5% of silicon, copper-chromium steel containing 0·15–0·18% of carbon, 0·5–0·8% of copper and 0·4% of chromium and difficulties encountered in avoiding a tendency to air-hardening and in welding high-tensile

steels are discussed at some length. Finally high-yield-strength low-carbon steels and the influence of titanium in restricting the hardening during welding of low-alloy structural steels are dealt with.

Materials in the Technique of Precision Machinery. K. Franz. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Dec. 18, pp. 1449–1452). Reference is made to chromium steels, nickel-chromium steels and chromium-molybdenum steels for structural purposes, and to high-sulphur and high-phosphorus free-cutting steels. In particular the special steels for permanent magnets are considered at length; the use of the nickel-aluminium magnet steels, with or without additions of titanium or cobalt, in the form of powder bonded with bakelite or rubber, is noted.

Co-operation of Designer and Iron Metallurgist in Replacing Structural Materials Hitherto Used by New Ones. A. Jünger. (Stahl und Eisen, 1937, vol. 57, Dec. 30, pp. 1445–1447). The author discusses the replacement of chromium-nickel steels by chromium-molybdenum steels, the introduction of economically more favourable alloys and of clad metals for corrosion- and heat-resisting purposes, the use of cast components and the maximum utilisation of the possibilities of welding and of surface treatment; in this way is indicated the economy in materials which may be effected by the collaboration of the designer and the metallurgist.

The Development of Special Steel with Consideration of the Raw-Material Position. E. Houdremont. (Metallwirtschaft, 1937, vol. 16, Nov. 26, pp. 1239–1248). The author discusses problems in connection with the necessity for economising in Germany in the use of certain alloy additions to steel, and the maintenance of the high mechanical properties of the steel while at the same time decreasing certain alloy additions or replacing them by more abundant elements or by those of domestic origin. Structural steels, tool steels, and corrosion-resistant steels are considered, the effects of varying the alloy additions being critically examined. The replacement, either partially or wholly, of nickel in alloy steels is specially discussed. Chromium-silicon, chromium-molybdenum, chromium and low-nickel chromium-manganese steels are among the types discussed. Graphical and tabular data regarding the mechanical and physical properties of the steels figure in the paper.

Steel and Iron in Shipbuilding and Marine Engineering. II.—Boiler, Reciprocating Engine and Turbine Construction. J. W. Donaldson. (Iron and Steel Industry, 1937, vol. 11, Dec., pp. 85–90). A continuation of a previous article. (*See* p. 150 A). The author compares the operating conditions of marine and land power plants. The use of 0·22–0·32% carbon steel for fire-tube and water-tube marine boilers is noted, together with the limited use for special boiler components of alloy and heat-resisting steels. For working pressures above the normal, up to 400–500 lb. per sq. in., higher carbon steels with ultimate stress values of 36–42 tons per sq. in. and a minimum elastic limit of 17 tons per sq. in. have been

introduced; nickel steels of similar properties have also been used. The special conditions under which boiler drums and tubes and superheaters operate call for corrosion- and heat-resisting properties of a high order; in the first instance copper-bearing, molybdenum-bearing or copper-molybdenum steels have been employed to a limited extent, while in the second higher alloy steels are finding increased application. The author also discusses the conditions obtaining in reciprocating engines and turbines, in turbine gearing and casing and in shafting, propellers and pumps; the steels best suited for each purpose are considered. Tabular data are presented.

Metals and Alloys used in Diesel Locomotive Cabs. E. F. Cone. (Metals and Alloys, 1937, vol. 8, Oct., pp. 271–275). The author considers the properties, treatment and specific applications of steels used in the superstructure and framework of Diesel locomotives. For the all-welded superstructure a plain carbon steel, S.A.E. 1020, is used for parts not highly stressed; stressed components are fabricated in a manganese-molybdenum steel containing carbon 0·13%, manganese 0·91% and molybdenum 0·51%. Tabular data are presented comparing the mechanical properties of the carbon and alloy steels referred to. Details regarding welding technique are given. For covering the framework, which is fabricated from manganese-molybdenum steels, stainless steel, sealed galvanealed ply-metal panel, or ply-metal with stainless steel on the exposed face and galvanealed metal on the interior face may be employed. The truck frame and bolster are cast in one piece in a 2·25% nickel steel and specially heat-treated. The choice of material for wheels is discussed at some length; the use of cast-steel wheels in the heat-treated condition and of rolled molybdenum-steel wheels is referred to. The construction of switching locomotives is also dealt with, the mechanical properties and heat treatment of the steels from which they are fabricated being discussed.

New Developments in High-Speed Steels Low in the Less-Readily-Available Alloying Elements. E. Houdremont and H. Schrader. (Technische Mitteilungen Krupp, 1937, vol. 5, Nov., pp. 227–239). The authors deal primarily with the development and properties of high-speed steels in which the tungsten is replaced wholly or in part by alloying elements which are cheaper or more readily available. After a preliminary discussion on the metallography and mechanical properties of high-speed steels in general, and on the reasons for attempting to find substitutes for the tungsten which such steels usually contain, investigations on new types of high-speed steel developed from this standpoint and containing lower tungsten contents in conjunction with vanadium or molybdenum or with the last metal entirely replacing the tungsten are described. The cutting properties of tools made from such steels and employed for rough turning are examined in relation to their composition; similarly, their performance in finish turning is discussed. The influence of the alloy additions on the forging and

heat treatment of the steel in the process of manufacturing the tool is considered at length with particular reference to the sensitivity of the materials to overheating and to decarburisation. Graphical and tabular data are included in the paper.

Historical Development of High Speed. H. C. Bigge. (Metal Progress, 1937, vol. 32, Oct., pp. 455–461). The author describes the evolution of the modern high-speed steel from the "self-hardening" steel of Mushet; the investigations of Taylor and White are discussed. Brief details are presented of current melting practice, and tabular data are included to show the development of contemporary analyses.

Some Tool Steels and their Applications. P. Mabb. (Metal Treatment, 1937, vol. 3, Winter issue, pp. 181–185). The author considers a comprehensive range of steels which, apart from those commonly classed as tool steels (such as the high-speed steels containing from 12 to 18% of tungsten), includes also case-hardening and nitralloy steels, crucible cast steels, oil- and air-hardening steels of various types and Armco iron. The heat treatment and processing of each class of steel are considered together with its special field or fields of application for tool making.

Investigations on Steel Strip for Tension Springs. H. Poellein. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 18, pp. 247–272). To determine the conditions for the manufacture of a high-duty spring steel, fifteen plain and four alloy steels, some of Swedish and some of German origin, prepared by various melting processes, were worked up into springs of uniform dimensions and subjected to a number of mechanical tests, a Swedish-steel spring being used as a standard of comparison. The melting and testing practices used are described in detail together with the analyses of the steels tested. Results are presented in graphical and tabular form.

The Behaviour of Expanded Tubes in Service. A. Thum and W. Mielentz. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Dec. 25, pp. 1491–1494). The authors discuss the use of expanded tubes in boilers and similar vessels. Reference is made to the mechanical properties of the metal subjected to heavy rolling during expansion, particularly in regard to the endurance limit, and to embrittlement by corrosion owing to the presence of reactive chemicals in the contents of the vessel.

The Metallurgical Story of Ford Brake Drums. E. F. Cone. (Metals and Alloys, 1937 vol. 8, Nov., pp. 303–306). The author describes the evolution of the special high-carbon steel brake drum employed on the Ford V-8 car. The steel contains carbon 1·55–1·7%, silicon 0·90–1·1%, copper 2·00–2·25%, manganese 0·70–0·90%, phosphorus 0·10% (max.), and sulphur 0·08% (max.). This material requires a special heat-treatment cycle, which is considered in detail, together with the mechanical properties obtained. The microstructure of the material is discussed with special

reference to the silicon and copper contents. The brake drums are produced in various foundries to Ford specifications as regards both composition and heat treatment; the equipment used is dealt with.

Modern Refrigeration Needs Modern Metallurgy. W. Mikulas and L. A. Philipp. (Metal Progress, 1937, vol. 32, Dec., pp. 755–760). Included in an account of the metals used in the manufacture of a refrigerating unit is a description of the material for and methods of manufacture of the cast-iron cylinder blocks, valve plates, cylinder heads, pistons and pulleys, and of the forged steel crankshafts. The cylinder blocks, except those cast in permanent moulds, are made of Meehanite iron. The iron commonly used contains 3·25–3·75% of carbon (total), 0·30–0·60% of carbon (combined), 1·7–2·7% of silicon, 0·50–0·70% of manganese, 0·25% of phosphorus and 0·10% of sulphur. Some account is given of the use of 0·5% molybdenum cast irons for experimental crankshafts. Steel crankshafts are forged in S.A.E. X-1020 or X-1315 steel, carburised and hardened to Rockwell C 62. Crankshafts of the largest commercial compressors are in S.A.E. T-1345 steel surface hardened by the " Tocco " induction-heating process to Rockwell C 60.

Study of the Condition of Metallic Surfaces which come into Contact in Machinery. (Société française des Mécaniciens, June 22, 1937 : Génie Civil, 1937, vol. 111, Dec. 18, pp. 527–529). Summaries are presented of the following papers : The Influence of Surface Conditions on the Resistance to Movement of Pressed Fits, by O. Kienzle; New Method of Determining the Condition of Machined Surfaces, by H. Tornebohm (an account is given of the " tetameter "); Relationship between Surface Condition and Optical Dispersion, by F. Canac; Condition of Metallic Surfaces—Its Determination and Influence on Resistance to Fatigue, by P. Bastien; Contribution to the Study of the Influence of Surface Conditions on Forced Fits, by P. Nicolau; The Importance of Surface Conditions, by A. Portevin; Surface Condition and Lubrication, by H. Brillié.

Standardisation of Iron and Steel Products. A. F. Webber. (Sheffield Society of Engineers and Metallurgists, Dec. 13, 1937). The author outlines the evolution of standard specifications for structural components and steel qualities, and then considers in more detail recent standards regarding the analyses of steels, welding operations, the uses and compositions of special and alloy steels, and test codes. Certain inherent difficulties encountered in or arising from standardisation are considered in the concluding section of the paper.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 156 A–158 A)

The Use of Chromic Acid in Electrolytic Etching of Iron and Steel. M. Baeyertz. (Transactions of the American Society for Metals, 1937, vol. 25, Dec., pp. 1185–1197). An electrolytic etching method is suggested in which the sample is treated anodically in 10% aqueous chromic acid. The method is applicable to plain and alloy steels and to the stainless iron-chromium and iron-nickel-chromium alloys. The technique of etching with this reagent is described.

Recent Progress in Industrial Radiography. H. R. Isenburger. (Iron Age, 1937, vol. 140, Nov. 25, pp. 43–45). The author discusses X-ray tube design, the penetrameter for testing exposures and the intensifying screen in connection with industrial radiography. Details are presented of a portable unit embodying the improvements and safety devices referred to in the article. The value of X-ray inspection in industry is emphasised.

The Detection of Faulty Jointing in Welded Seams by Means of X-Rays. M. Widemann. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Dec. 4, pp. 1403–1406). The author considers briefly the theoretically minimum dimensions of fissures or oxide films which may be detected under different conditions by X-ray methods in welded seams, discusses the origins of faulty adhesion between component parts of the weld and cites various types of faults, and then discusses in detail the results of experimental investigations on the determination of faults in welded seams in St. 37 steel. The efficacy of the method and limiting conditions are dealt with. Data are presented in tabular form.

Exposure Chart for Radiography of Steel. H. R. Isenburger. (Metal Progress, 1937, vol. 32, Oct., p. 498). Charts are presented for computing exposures required in the industrial radiography of steel.

Peculiar Phenomena in the Magnetic Testing of Materials. C. Holtschmidt. (Zeitschrift des Vereines deutscher Ingenieure, 1937, vol. 81, Nov. 27, p. 1374). The author discusses briefly certain anomalous results obtained when testing ferromagnetic materials by magnetic methods involving their treatment in the magnetised condition with a suspension of iron powder in petroleum. This note is designed to supplement observations made in the author's original discussion on this method of testing materials. (*See* Journ. I. and S.I., 1937, No. II., p. 195 A).

The Formation of Inclusions in Steel. H. Wentrup. (Stahl und Eisen, 1937, vol. 57, Dec. 16, pp. 1404–1407). (*See* Journ. I. and S.I., 1937, No. II., p. 134 A).

The Morphology of Inclusions in Siderurgical Products. R. Castro and A. Portevin. (Revue de Métallurgie, Mémoires, 1937, vol. 34, May, pp. 307–326). A full translation into French of the third and last paper by these authors on the morphology of inclusions in siderurgical products which was originally presented to the Iron and Steel Institute and published in the Journ. I. and S.I., 1937, No. I., pp. 223 P–244 P. (*See also* Journ. I. and S.I., 1937, No. I., p. 145 A).

Orientation Habit of Martensite. A. B. Greninger and A. R. Troiano. (Nature, 1938, vol. 141, Jan. 1, p. 38). The authors claim to have demonstrated that martensite in quenched plain high-carbon steels is not parallel to the octahedral {111} planes of the austenite lattice. The poles of planes delineated by martensite midribs deviate by approximately 2–3° from {421} of the austenite lattice. The authors outline their experimental procedure.

The Microstructures of Mo-Max and 18-4-1 High Speed Steels Compared. R. G. Kennedy, jun. (Metals and Alloys, 1937, vol. 8, Oct., pp. 289–293). The author discusses and compares the microstructures under different conditions of heat treatment of "Mo-Max" high-speed steel containing carbon 0·8%, chromium 3·65%, tungsten 1·35%, molybdenum 9·01%, vanadium 1·23%, and of "18/4/1" containing carbon 0·70%, tungsten 18·0%, chromium 3·90% and vanadium 1·04%.

The Relation Between the Grain Areas on a Plane Section and the Grain Size of a Metal. J. J. B. Rutherford, R. H. Aborn and E. C. Bain. (Metals and Alloys, 1937, vol. 8, Dec., pp. 345–348). The statistical distribution of apparent grain sizes as observed on a plane section may, unless logically considered, give an incorrect impression of the real grain size, in so far as more smaller grains will be indicated than really exist. It is postulated that the smaller grain sizes should be ignored unless present in clusters and to the extent of, say, 10% of all the grain sections. It is seldom of value to report more than one grain size unless there exist considerable quantities of two sizes, in which case it is indicated that the temperature-time schedule has been such that marked coarsening has begun but has not proceeded to completion.

On the Influence of the Cooling Velocity on the Transformations in Steels. I.—A New Method of Investigating Transformation Processes at High Cooling Velocities and the Influence of the Cooling Velocity on the Transformations in Carbon Steels. F. Wever and A. Rose. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1937, vol. 19, No. 20, pp. 289–298). A new method of determining transformation temperatures at high cooling rates is described; it involves the use of an electro-cardiograph actuated by thermocouples mounted on the specimen, the beam from the mirror of the cardiograph being reflected on to a fixed sensitised plate. The blackening of the plate is determined photometrically and corresponds directly to the reciprocal of the radial velocity of

the reflecting mirror at any point, *i.e.*, to the reciprocal of the velocity of temperature change. The mathematical principles of the method are explained at length. Tests are described which demonstrate the applicability of the apparatus. The transformations in carbon steels are depressed discontinuously in three stages to lower temperatures with increasing cooling rates, hence in this case the behaviour of the steels at raised cooling rates can be completely and simply described by three supercooling diagrams characterised by temperature ranges of pearlite formation down to about 650° C., and 500° C. respectively in the case of the first two. The change from equilibrium conditions to the three stages of supercooling is accompanied by structural alterations and by modifications in mechanical properties.

A New Equilibrium Diagram for the System Fe-C. I. I. Iitaka. (Scientific Papers of the Institute of Physical and Chemical Research, 1937, vol. 33, Nov., pp. 273–287). The author discusses at length the two opposing concepts regarding the iron-carbon system, namely, the hypothesis which denies the existence of the austenite-graphite eutectic and that which insists upon the possibility of graphite separating out as such from molten iron and thus giving rise to the eutectic. The "single" and "double" equilibrium diagrams based upon the first and second theories respectively are examined and criticised; experimental evidence is brought forward showing that the fundamental assumptions of the single diagram are untenable. A consideration of supercooling phenomena leads to the conclusion that the double diagram is not strictly consistent. A new diagram is then presented which is in accordance with experimental observations and which incorporates the desirable features of the single and double types previously discussed.

Structural and Hardening Characteristics of Some Iron-Cobalt-Tungsten Alloys. W. P. Sykes. (Transactions of the American Society for Metals, 1937, vol. 25, Dec., pp. 953–1012). In the binary iron-tungsten alloys the iron-rich α solid solution exists in the body-centred cubic form at all temperatures below the freezing point. On substituting cobalt for part of the iron, the α solid solution is replaced by the face-centred cubic γ solid solution existing above about 950° C.; rapid cooling from above this temperature causes grain refinement in the γ solid solution similar to that occurring in austenite in steel. The diffusion rate of tungsten, however, is relatively low, and no precipitation of the tungsten-rich phase (corresponding to cementite in steel) takes place until the quenched alloy is heated to approximately 300° C. By reheating or ageing at 600° C. the hardness is increased from Rockwell C 38 to C 65 within 15 min., and attains a value of C 69 in about 1 hr. Isothermal decomposition of the γ solid solution gives structures resembling those obtained in steel after similar treatment, although for the production of any given structure the ternary alloys require temperatures about 300° C. above those required by carbon steel.

Alloys containing 30% of cobalt and 20% of tungsten, on isothermal decomposition above 600° C., yield pearlitic structures; at temperatures below 500° C. an acicular structure is obtained; at about 550° C. decomposition does not begin within a period of 100 hr. Small additions of elements such as nickel, chromium or vanadium retard the decomposition of the γ solid solution, which may then persist even at room temperature.

The Alloys of Iron and Zinc. W. D. Jones. (Metallurgist, 1937, vol. 11, Dec., pp. 84–86). The author presents a critical review of the work of Bablik and others upon the metallography and mechanism of formation of the iron-zinc alloys produced by the attack of molten zinc upon the surface of steel. The phases demonstrated by Bablik are identified by the author with those observed or postulated by other investigators and it is pointed out that certain of Bablik's conclusions do not entirely agree with the micrographs presented to support them. The author summarises the anomalies referred to. (*See also* p. 26 A).

CORROSION OF IRON AND STEEL

(Continued from pp. 159 A–163 A)

Corrosion Probability. R. B. Mears and R. H. Brown. (Industrial and Engineering Chemistry, 1937, vol. 29, Oct., pp. 1087–1091). The effect of several external variables on corrosion probability and intensity of attack for aluminium specimens has been investigated. An increase in the area of the metal exposed increases the probability of attack but decreases the number of breakdowns per unit area. The different behaviours of iron and aluminium are noted, particularly in regard to the spread of corrosion over the whole of the exposed area in the case of the first metal and to its remaining localised at the site of initial attack in the case of the latter.

The Pitting of Stainless Steel and the Insolubility of Ferric Ion in Sea Water. W. A. Wesley and C. H. Lindsley. (Metals and Alloys, 1937, vol. 8, Dec., pp. 335–337). After a brief reference to the action of acidified ferric chloride in causing pitting of stainless steels and to the similarity between this action and the slower effects manifested by sea-water attack, the authors describe experiments in which it is shown that the solubility of the ferric ion in sea water is less than one part per million at a *p*H value of more than 3; hence the theory that iron salts in sea water initiate pits is untenable. It is noted that the iron content of sea water is very low. Again, whilst ferrous chloride is soluble in sea water below *p*H 7, it is readily oxidised and precipitated as ferric hydroxide by the action of dissolved air. The mechanism of the sea-water pitting of stainless steel is discussed in the light of the foregoing observations.

Corrosion Phenomena in Iron-Chromium-Aluminium Alloys. W. Baumann. (Metallwirtschaft, 1937, vol. 16, Dec. 3, pp. 1267–1269). The results of experiments on the corrodibility of wires made of steels containing from 20 to 30% of chromium, 3 to 6% of aluminium, and, in one case an addition of 2% of cobalt, in contact with moist magnesia-containing asbestos, indicate that the rapid attack is due to the action of the magnesium hydroxide which removes aluminium and iron from the alloy, leaving a skeleton of chromium. It is noted that in 16 hr. the degree of attack by such asbestos is equal to that attained after 1000 hr. exposure to 1·0% aqueous sodium chloride.

Comparison Between Tests in the Sea and in the Laboratory on the Marine Corrosion of some Extra-Mild Steels—Plain and with Low Alloy Additions. A. Portevin and E. Herzog. (Métaux et Corrosion, 1937, vol. 12, Nov., pp. 201–209). The results of comparative corrosion tests on specimens of basic open-hearth and basic Bessemer mild steels and low-chromium-aluminium mild steel

exposed to the action of sea-water and the laboratory salt spray are discussed. The classification based on loss of weight demonstrates that both tests yield results which, qualitatively at least, are concordant; the addition of chromium and aluminium decreases marine corrosion by $\frac{2}{3}$ to $\frac{7}{8}$, particularly in immersion tests. The most marked divergences are exhibited by tests in the salt spray and in a marine atmosphere; the decrease in corrosion by 50% and more shown by the chromium-aluminium steel when subjected to the salt spray is reduced to a decrease of only 10–30% when the material is exposed to a marine atmosphere. The distribution of attack is more irregular in immersion tests than in those involving attack by marine atmospheres. Laboratory salt-spray tests duplicate the pin-point attack brought about by marine atmospheres, but alternating immersion tests do not result in the pitting and similar modes of attack characteristic of sea-water immersion tests. Analyses of the products of corrosion indicate that silica and calcium carbonate are adsorbed at the surface of steels in sea water and fresh water; this phenomenon cannot be reproduced in laboratory immersion or alternating-immersion tests. Chromium-aluminium steel possesses a surface more favourable to this adsorption than the basic steels. The chemical condition of the surface of a steel is of great importance in connection with adsorption phenomena. Laboratory corrosion tests reproduce in part only the corrosion processes occurring in natural salt or fresh waters. This is not to be taken as indicating that laboratory tests are valueless, but that they might be modified to resemble more closely the processes of attack observed in field tests.

Testing the Corrosion Resistance of Welds. (Welding Industry, 1937, vol. 5, Dec., pp. 385–387; 1938, Jan., pp. 433–435). The significance of the structure of a weld in relation to the electrochemical theory of corrosion is briefly discussed. A testing apparatus for determining the corrosion resistance of a number of specimens simultaneously under conditions of periodic immersion in a corroding medium is described, the somewhat critical value attaching to the concentration of the acid solution employed being considered in detail. Tests on welds in a 0·08% carbon mild steel are examined. The quantitative test specimens of Searle and Laque are described and some experiments carried out to determine the corrosion resistance of various commercial grades of electrodes are discussed in detail. Graphical and tabular data are presented.

Intercrystalline Cracking of Steel in Aqueous Solution. W. C. Schroeder, A. A. Berk and R. A. O'Brien. (Metals and Alloys, 1937, vol. 8, Nov., pp. 320–330). The authors discuss a series of tests carried out on mild steels regarding the incidence of intercrystalline cracking under various conditions of stress and in various corrosive media. Tension tests carried out in sodium hydroxide solutions at 250° C., and intercrystalline cracking in sodium nitrate solutions, sodium hydroxide solutions and in solutions of

nitric acid are dealt with. It is concluded that to be destructive, and productive of intercrystalline cracking, the corrosive media must produce a non-continuous film on the steel and attack the grain boundaries.

Rapid Corrosion Test with Simultaneous Mechanical Stressing. P. Brenner and W. Roth. (Metallwirtschaft, 1937, vol. 16, Dec. 10, pp. 1295–1299). An apparatus is described in which tests may be made of the resistance of metals and alloys to corrosion coupled with mechanical stress. Results may be obtained in a few days or even hours, and the apparatus is capable of detecting fine differences in corrosion resistance. Aqueous sodium chloride containing free hydrochloric acid is employed as the corrosive medium.

Soil-Corrosion Studies, 1934. Bituminous Coatings for Underground Service. K. H. Logan. (Journal of Research of the National Bureau of Standards, 1937, vol. 19, Dec., pp. 695–740). A summary is presented of the results of studies on bituminous coatings for pipe-lines carried out between 1922 and 1935. The performance of a protective coating is controlled by the soil conditions to which it is subjected. The shrinkage and the relative density of the soils are important factors in the distortion of coatings. Distortion is very severe in dense soils which undergo marked changes in volume with changes in moisture content. Because of the effect of soil characteristics on coating behaviour, coatings should, where practicable, be selected with reference to soil conditions. Whilst no coating completely prevented corrosion under all soil conditions for as long as four years, loss of metal was usually considerably reduced. Coatings which are somewhat porous, such as cut-backs and asphalt emulsions, are effective in preventing pitting in well-aërated soils. The thickness of the coating is important; thin bituminous coatings are unsuitable for severe soil conditions. For coatings of equal thickness, coal-tar-base compounds absorb less water and insulate better than asphalt-base coatings, but in general the former are more affected by soil stresses and thermal and mechanical shocks. Shields and reinforcements reduce the depth of the deepest pit to a great extent during the first few years of exposure, probably because of their resistance to soil stress, although their relatively great thickness may be a factor. Asbestos felt offers more permanent protection and reinforcement to bituminous materials than rag felt. No bituminous coating or coating material is inherently greatly superior to all others; it is possible to secure similar results by several methods. The life of protective coatings is somewhat uncertain since there are few detailed records covering periods of more than five years. Suitable bituminous coatings materially reduce corrosion losses, but pipe coatings free from imperfections and chances of injury cannot be expected.

Steel and Reinforced-Concrete Masts for Power Lines. H. V. Bronneck. (Montanistische Rundschau, 1937, vol. 29, Dec. 16, Stahlbau Technik, pp. 5–7). The susceptibility of steel masts for

power lines to the influence of the atmosphere and of furnace waste gases is noted, and the need for regular repainting or retreatment of the metal surface is stressed. The advantages and disadvantages of reinforced concrete masts are discussed and the use of copper-bearing steel for reinforcing is referred to.

The Destruction of Metallic Structural Materials by Water Impact. M. Frh. von Schwarz and W. Mantel. (Korrosion und Metallschutz, 1937, vol. 13, Oct.–Nov., pp. 375–379). The authors discuss the mechanics of cavitation and wet-steam erosion phenomena and consider briefly the progress of the attack upon metallic surfaces by water under relatively high pressure. The relationship between certain mechanical properties and resistance to erosion of this type is examined, and it is noted that hardness alone does not necessarily confer immunity. The conditions for maximum resistance are summarised, and the results of experiments upon various groups of metals, including cast and forged plain and low-alloy steels and special steels, are dealt with at length.

ANALYSIS

(Continued from pp. 95 A–97 A)

Modern Methods of Alloy Steel Analysis. B. Bagshawe. (Proceedings of the Staffordshire Iron and Steel Institute, 1936–37, vol. 52, pp. 116–142). After a preliminary review of the development of the modern technique for analysing alloy steels and noting the problems to which interfering elements give rise and the value of selective organic reagents, the author considers the determination of manganese and chromium, cobalt, chromium in stainless steels, chromium in small amounts by colorimetric methods, titanium by colorimetric methods, copper, molybdenum, aluminium (and alumina), nitrogen, arsenic (reference is made to the precipitation of elementary arsenic by hypophosphorous acid), tantalum and niobium (columbium), zirconium, selenium, and beryllium. The trend of future developments is briefly examined.

Potentiometric Method for the Determination of Molybdenum and Copper Together in Steel. E. Shaefer. (Archiv für das Eisenhüttenwesen, 1937, vol. 11, Dec., pp. 297–302). A method and apparatus for the potentiometric determination of copper and molybdenum, either alone or together, in steels are described. Titanous chloride is employed for the titration.

The Rapid Determination of Copper in Mild Steel. T. P. Hoar. (Analyst, 1937, vol. 62, Nov., pp. 788–790). The author describes the colorimetric estimation of copper in mild steel with diethyldithiocarbamate. Tests on the accuracy of the method are also described.

Determination of Chromium in Ferrochrome. G. F. Smith and C. A. Getz. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Aug. 15, pp. 378–381). High- and low-carbon ferro-chromium is rapidly dissolved by 85% phosphoric acid. A mixture of perchloric and sulphuric acids at 210° C. is used as an oxidising agent, while hydrogen peroxide formed by this latter process may be removed with permanganate or persulphate.

Fractional Vacuum-Fusion Analysis for Determination of Oxygen in Steel. S. L. Hoyt and M. A. Scheil. (American Institute of Mining and Metallurgical Engineers, 1937, Technical Publication No. 821: Metals Technology, 1937, vol. 4, Oct., No. 7). The authors discuss the technique of the fractional vacuum-fusion method for determining gases in steels, examine the sources of error due to gases evolved from the crucible, and comment on the use of the polarising microscope for identifying inclusions in steel and so checking and amplifying the results of the analysis.

Photo-Colorimetric Determination of Vanadium in Iron Ores and Slags. H. Pinsl. (Archiv für das Eisenhüttenwesen, 1937, vol. 11,

Dec., pp. 293–296). A photo-colorimetric method for determining small quantities of vanadium in iron ores and slags in the presence of any other elements which may be present (including titanium, chromium and small amounts of molybdenum) is described. The material is fused with sodium peroxide, the digest being treated with nitric acid; the subsequent determination and the preliminary treatment occupy a period of 30 to 40 min.

An Investigation of the Zinc Oxide Separation as Applied to the Determination of Manganese in Special Cast Irons. E. C. Piggott. (Analyst, 1937, vol. 62, Dec., pp. 860–863). To avoid interference from phosphorus, and to prevent errors introduced by the presence of chlorides and the formation of the unstable silver-bismuthate/nitric-acid complex in certain other methods, a double zinc-oxide separation can be used which is suitable for application to the determination of manganese in special cast irons.

Dipotassium Sodium Cobaltinitrite and its Application to the Gravimetric Determination of Cobalt. C. F. Cumbers and J. B. M. Coppock. (Journal of the Society of Chemical Industry, 1936, vol. 56, Oct., pp. 405 T–407 T). The extent of hydration and the conditions of formation of di-potassium sodium cobaltinitrite are studied and a rapid method of determining cobalt gravimetrically by means of this complex is presented. Notes are appended on the determination of potassium as cobaltinitrite and of cobalt as a derivative of 8-hydroxyquinoline.

Principles of the Quantitative Determination of Traces. E. Reichel. (Berg- und hüttenmännisches Jahrbuch der montanistischen Hochschule in Leoben, 1937, vol. 85, Nov. 30, pp. 234–238). The author discusses the basic principles underlying the determination of traces of (metallic) elements. The detection and estimation of nickel ions is referred to and the use of organic reagents noted.

On the Preservation of Ammonium Molybdate Reagent. S. Saitô. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Sept., pp. 253–260). The author examines certain suggested reasons for the instability of ammonium molybdate solutions. A 2·5% solution of ammonium molybdate in 5*N* nitric acid is suggested as most satisfactory; the molybdenum concentration remains constant and the solution is photostable.

Recent German Advances in Spectrographic Analysis. E. H. S. van Someren. (Metallurgist, 1937, vol. 11, Dec., pp. 86–88). A critical summary is presented of recent progress in Germany in the technique and applications of spectrographic analysis. Reference is made to the work of Ramb and of others. (*See also* p. 96 A).

On Quantitative Spectrum Analysis: Investigation of the Vaporisation Process on Metallic Electrodes Under the Influence of a High-Tension Discharge. H. Winter. (Zeitschrift für Metallkunde, 1937, vol. 29, Oct., pp. 341–351). After a preliminary discussion on the technique of quantitative spectrum analysis, the author proceeds

to a detailed account of the effects of spark discharges of different types between metal electrodes, the effects being determined by metallographic examination. The effects of the pre-sparking of electrodes on the accuracy of quantitative results are also investigated. It is concluded that experimental errors are not difficult to avoid in quantitative analysis, but that errors due to heterogeneity of the sample require special care.

A New Method of Quantitative Emission-Spectrum Analysis. A. Rivas. (Beiheft zu den Zeitschriften des Vereins deutscher Chemiker, No. 29: Angewandte Chemie, 1937, vol. 50, Dec. 4, pp. 903–905). The disadvantages of spectrum analysis associated with the use of the material to be analysed in the form of electrodes are obviated by the use of carbon electrodes treated with a solution of the material in question which is allowed to dry out before the electrodes are used. Accuracy and reproducibility are discussed and photometric observations considered. Quantitative analysis by the arc technique described is shown to be very accurate. Reference is made to the determination of nickel, aluminium, copper and molybdenum in iron.

Report on the Sampling of Coal with Special Reference to the Size-Weight-Ratio Theory. E. S. Grumell. (British Standards Institution, No. 763–1937). The errors involved in the reduction and analysis for ash content of gross samples of coal have been examined and their magnitude has been determined on three samples of Northumberland coal passing a $\frac{1}{4}$-in. mesh. Results have been examined mathematically and show reasonable statistical uniformity. It is demonstrated that the crushing and sub-division of gross samples for analysis may introduce considerable errors, to avoid which a process of systematic crushing and screening has been suggested. The use of mechanical samplers is advocated; a riffle sampler gives little or no trouble arising from segregation and can also be used as a mixing device. For accurate work, determinations of ash should be made in duplicate. A systematic error is introduced by varying the weight of the small portion of coal ashed in the muffle or by altering the procedure adopted for its analysis; this is presumed to be due to the presence of carbonates and pyritous residues. Sulphation of coal ash does not reduce the degree of error involved in the analytical determination. It is suggested that errors due to carbonates might be reduced by raising the muffle temperature from 750° C. to 825° C.

Determination of Pyrites Sulphur in Bituminous Coals. W. Mantel and W. Radmacher. (Glückauf, 1937, vol. 73, Oct. 30, pp. 989–993). After reviewing briefly the literature dealing with the determination of pyrites sulphur in coals, the authors present the results of pyrites-sulphur determinations on certain selected bituminous coals by the usual methods. A rapid reduction-titration method is described which yields reproducible results.

BOOK NOTICES

(Continued from pp. 164 A–167 A)

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Transactions, vol. 125. Iron and Steel Division 1937.*" 8vo, pp. 602. Illustrated. New York, 1937: The Institute.

The American Institute of Mining and Metallurgical Engineers issues two annual volumes of Transactions of interest to metallurgists, one devoted chiefly to ferrous metallurgy and the other to non-ferrous metallurgy. Papers dealing with the fundamentals of metallurgy cannot be relegated on any logical basis to one or the other volumes, consequently papers of interest to those engaged primarily in ferrous metallurgy may therefore be found also in the Institute of Metals Division volume.

The present volume contains the papers presented before the Iron and Steel Division at the Annual Meeting of the Institute in New York in February 1937, and at the Joint Meeting with the Institute of Metals Division in Cleveland in October 1936. The volume opens with a report of the Howe Memorial Lecture delivered by P. D. Merica, in which the author deals with the progress in the improvement of cast iron and the use of alloy cast iron, and is followed by studies on blast-furnace operations, determination of gases in metals, ingot structure, grain-size and the constitution and structure of ferrous alloys. Abstracts of all the papers contained in this volume are to be found in Section II. of the *Journal of the Iron and Steel Institute.*

The proceedings of the Open-Hearth Conference, promoted by the Open-Hearth Committee of the Iron and Steel Division, are published separately in a volume entitled "1937 Open-Hearth Proceedings."

ATKINS, E. A. "*Practical Sheet and Plate Metal Work.*" Fourth ed. 8vo, pp. viii + 604. Illustrated. London, 1937: Sir Isaac Pitman & Sons, Ltd. (Price 7*s.* 6*d.*)

In the compass of some six hundred pages the author has presented a wealth of accurate and assimilable information essentially representative of current practice. The high standard aimed at in the earlier editions has been maintained, and the text has been considerably amplified. The book is divided into forty-six chapters, of which the majority deal each with a specific type of work, the earlier chapters covering general operations such as the development of elbows, T-pieces and transformer pieces. In every case the preparation of the necessary patterns is fully discussed, the explanatory matter in the text being amplified by the provision of diagrams and illustrations of which there are some three hundred and fifty. Chapters thirty-five and thirty-eight, covering the jointing of sheet metal by soldering and analogous methods and by riveting, the surface treatment of metals and the physical and mechanical properties of metals, are to be commended; they supply to the practical man fundamental information in a brief form concerning the materials in which he works. With an ever-increasing array of alloys at his disposal, each requiring special treatment and each possessing special advantages in certain fields of application, it is essential that he should have this knowledge at his

command. Possibly the only section of the book to which a metallurgist might take slight exception is that dealing with alloys on pages 572 to 574. The figures given for the composition of stainless iron and steel, for example, require some qualification if misconceptions are to be avoided, whilst no mention is made of magnesium alloys, which, at no very distant date, will undoubtedly form an important material in certain branches of the sheet-metal working industries. The specialised technique required for working it would have justified the inclusion of a note upon its properties. In an appendix will be found specimen examination papers of the City and Guilds of London Institute and of the Union of Lancashire and Cheshire Institutes.

COMBER, A. W. "*Magnesite as a Refractory.*" 8vo, pp. xii + 114. Illustrated. London, 1937: Charles Griffin & Co., Ltd. (Price 4*s.*)

The wide and increasing use of magnesite refractories and the relative inaccessibility of literature devoted to a study of the material and its properties and applications justify the appearance of this excellent little book. In it the author has succeeded in bringing together a surprisingly detailed account of the working-up of the raw material and the fundamental principles underlying this process and the industrial applications of the finished product. The first chapter deals with early experiments with magnesite as a refractory; a brief résumé of the nomenclature employed in connection with the subject is included in this section of the book. In the two following chapters the mineralogy and sources of the raw material are considered. Chapters IV. to VII. present an account of industrial practice in regard to the calcination of the raw magnesite and its manufacture into bricks, while the chemical and physical properties of the finished product are examined in Chapter VIII. Chapter IX. deals briefly with the development, production and properties of electrically-fused magnesite. A comprehensive summary of the uses of magnesite in the steel industry is given in the succeeding chapter, whilst other uses, particularly for lining various types of furnaces for the refining of copper, are rapidly surveyed in Chapter XI. Magnesite resources of the British Empire and factors controlling their development are discussed in the concluding chapter. Two appendices are included, one dealing briefly with the chemical composition of the raw and processed material, the other consisting of references. The book is amply illustrated.

IRON AND STEEL INSTITUTE. "*Carnegie Scholarship Memoirs,*" vol. XXVI. Edited by K. Headlam-Morley. 8vo, pp. ix + 174. Illustrated. London, 1937: The Institute. (Price 16*s.*)

The Memoirs contain the results of original research work in the metallurgy of iron and steel, carried out by research workers with the aid of grants made by the Iron and Steel Institute from the Andrew Carnegie Research Fund. The present volume contains the following: The Effects of Torsional Overstrain on the Physical Properties of some Typical Spring Steels, and Its Influence on the Shear Stresses in Helical Springs, by L. E. Adams; Investigations on Basic Refractories with Particular Reference to their Use in the Lining of Induction Furnaces, by C. Booth and W. J. Rees; "Yielding" Phenomena and Distortion in Iron, Steel, Aluminium Alloy and Other Metals under Stress, by E. W. Fell; The Relationship between the Microstructure and the Adherence of Scale Deposit, by R. Griffiths.

"*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung zu Düsseldorf.*" Herausgegeben von Friedrich Körber. Band xix. La. 8vo, pp. 315. Illustrated. Düsseldorf, 1937: Verlag Stahleisen, m.b.H. (Price 33 marks.)

Metallurgists will welcome the appearance of the new volume of the *Mitteilungen*, which records the results of important research work carried out at the Kaiser-Wilhelm-Institut für Eisenforschung under the direction of Dr. Friedrich Körber. The present volume contains the following twenty-four reports: The Thermochemistry of Alloys. I. Direct Determination of the Heats of Formation of the Alloy Series Cobalt-Silicon, Iron-Aluminium, Cobalt-Aluminium, Nickel-Aluminium, Copper-Aluminium and Antimony-Zinc for the As-Cast Condition, by W. Oelsen and W. Middel; The Application of the Polarograph in the Steelworks Laboratory. I. The Determination of Copper, Nickel and Cobalt together in Steels, by G. Thanheiser and G. Maassen; The Transformation Kinetics of Austenite. VI. The Decomposition of Austenite in Carbon Steels, I, by F. Wever and H. Hänsel; The Reproducibility of the Results of the Determination of Elastic Stresses by X-Rays, by H. Möller and F. Gisen; The Cold-Deformation of the Surface of Materials in Different States of Preparation, by H. Möller and A. Roth; Hot-Rolling Tests on Carbon and High-Alloy Steels under Various Rolling Conditions, by A. Pomp and G. Weddige; The Testing of Magnet Steels, by H. Lange; Mechanical Properties of Rope Wire in the Temperature Range from $+20°$ to $-50°$, by A. Pomp and A. Krisch; Contribution on the Determination of Gases in Steel by the Hot Extraction Method, by G. Thanheiser and H. Ploum; The Direct Photo-Electric Determination of Manganese and Chromium in Steels, by G. Thanheiser and J. Heyes; The Measurement at Half Maximum Intensity of X-Ray Interference Fringes, by H. Möller and A. Roth; Stress Measurements on Welded and Cold-Worked Test-Pieces by Means of X-Rays, by H. Möller and A. Roth; On the Thermochemistry of Alloys. II. Direct Determination of the Heats of Formation of the Ternary Alloys Iron-Nickel-Aluminium, Iron-Cobalt-Aluminium, Copper-Nickel-Aluminium, Iron-Aluminium-Silicon, together with a Series of Alloys of the Copper-Manganese-Aluminium System, by F. Körber, W. Oelsen and H. Lichtenberg; On the Oxidation of Steel Wire and its Influence on Subsequent Operations, by F. Körber and W. Asbeck; Research on the Progress with Respect to Time, of Stress, Elongation, and Velocity of Elongation in the Tensile Test, Particularly at the Yield Point, by A. Pomp and A. Krisch; The Course of the Austenitic Transformation in the Supercooled Condition, according to Investigations on Pure Carbon Steels, by H. Lange and H. Hänsel; On the Thermochemistry of Alloys. III. The Heats of Formation of the Binary Alloys Iron-Antimony, Cobalt-Antimony, Nickel-Antimony, Cobalt-Tin, Nickel-Tin, Copper-Tin, and Copper-Zinc, Prepared by Mixing the Molten Metals, by F. Körber and W. Oelsen; Comparative Investigation of the Mechanical Properties of Nickel-Bearing and Nickel-Free Steels, with Particular Regard to their Behaviour under Vibratory Stress, by A. Pomp and M. Hempel; Fatigue Testing of Steel Wires under Varying Tensile Stress. I. Influence of the Method of Manufacturing the Wire on the Strength under Fluctuating Tensile Stress, by A. Pomp and M. Hempel; Investigations on Steel Strip for Tension Springs, by H. Poellein; Behaviour of Welded and Bolted Rigid Joints under Static and Alternating Stress, by F. Körber and M. Hempel; The Influence of the Cooling Velocity on the Transformation in Steels. I. A New Method of Investigating Transformation Processes at High Cooling Velocities and the Influence of the Cooling Velocity on the Transformations in

Carbon Steels, by F. Wever and A. Rose; The Hydrogen Brittleness of Carbon Steels in Relationship to the Amount of Hydrogen Absorbed, by P. Bardenheuer and H. Ploum; The Conversion of Lattice Constants into Stresses when Measuring Stresses by Means of X-Rays, by H. Möller and G. Strunk. Abstracts of all the above-mentioned reports are to be found in Section II. of the *Journal of the Iron and Steel Institute.*

TRINKS, W. "*Supplement to Roll Pass Design* (*Volumes I. and II.*)." First edition. 8vo, pp. 88. Illustrated. Cleveland, Ohio, and London, 1937: Penton Publishing Co. (Price 6*s.* 3*d.*)

The author's well-known treatise on roll-pass design was first written in 1930, and was revised in 1933. As the author states in his preface, so much new information is now available that a new edition is in order. Almost all of the old material, however, is perfectly good, and it does not seem right to make progressive roll designers buy new books which contain that which is in the old edition plus that which is new. For that reason, the present supplementary volume was written. Taken by itself, the new work is a collection of disconnected information, and is useful only in conjunction with the previous edition; references, wherever possible, are made to the pages of the old volumes on which the new material belongs. The supplementary volume, together with the two volumes of the previous edition, form the most complete and up-to-date work on roll-pass design available to rolling-mill engineers.

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REFRACTORY MATERIALS

(Continued from pp. 171 A–172 A)

A Note on Petrographic Methods Applied to the Study of Silica Bricks. V. L. Bosazza. (Transactions of the Ceramic Society, 1938, vol. 37, Jan., pp. 1–5). The author discusses the preparation of large thin sections of silica refractories, and the microscopic examination (with polarised light and with the camera-polaroid combination in conjunction with the wide-field binocular-type microscope) and the petrographic study of the sections so prepared.

Olivine and Forsterite Refractories in America. F. A. Harvey and R. E. Birch. (Industrial and Engineering Chemistry, 1938, vol. 30, Jan., pp. 27–32). After a brief preliminary account of the chemistry, mineralogy and physical properties of forsterite and the olivines, particularly with regard to their availability and suitability as industrial refractories, the authors summarise the properties of forsterite refractories and describe at length some practical applications, including that for the end walls of basic open-hearth steel furnaces and for the lining of rotary kilns for roasting dolomite.

Olivine and Forsterite Refractories in Europe. V. M. Goldschmidt. (Industrial and Engineering Chemistry, 1938, vol. 30, Jan., pp. 32–34). The development of forsterite refractories is outlined and their gradually extending industrial use discussed, together with the evolution of industrial methods of producing them. Reference is made to the physical properties of forsterite refractories, including their resistance to spalling, and to some recently developed modified types of this refractory.

The Action of Carbon Monoxide on Refractory Materials. Part III.—Experiments with Laboratory-Prepared Specimens. W. Hugill, H. Ellerton and A. T. Green. (Transactions of the Ceramic Society, 1938, vol. 37, Jan., pp. 6–11).

The Action of Carbon Monoxide on Refractory Materials. Part IV.—The Deposition of Carbon on Certain Ferruginous Materials. W. Hugill, H. Ellerton and A. T. Green. (Transactions of the Ceramic Society, 1938, vol. 37, Jan., pp. 12–16). The authors present the results of an investigation of the deposition of carbon on four types of iron-bearing material, namely, hematite, pyrites, magnetite and an iron-oxide/clay fusion, in an atmosphere of carbon monoxide at 500°

Savings with Insulating Refractories. J. G. Coutant. (Heat Treating and Forging, 1937, vol. 23, Dec., pp. 630–631). The author discusses the heat balance of furnaces and the part played by the heat capacity of the linings in occasioning losses in the effective heating capacity. The advantages of insulating refractories are pointed out.

FUEL

(Continued from pp. 173 A–177 A)

New Power Plant for South Works of Carnegie-Illinois. (Blast Furnace and Steel Plant, 1937, vol. 25, Dec., pp. 1301–1303). (*See* p. 173 A).

Study of Equipment for Automatic Control. G. Jungnitz and M. Wulfinghoff. (Chaleur et Industrie, 1937, vol. 18, Dec., pp. 525–530). The principles of automatic controlling devices for heating equipment are considered from the mathematical and physical standpoints.

Thermal Balance and Heat Losses through Walls. (Centre d'Études Thermiques, Nov. 9, 1937: Chaleur et Industrie, 1937, vol. 18, Dec., pp. 531–534). A report is presented, together with discussion, of a meeting devoted to the consideration of the heat balance and heat losses through the walls of basic open-hearth furnaces. Data are given which refer to experiments on two of these furnaces at Rombas, France.

Efficiency and Heat Balances. R. Martin. (Chaleur et Industrie, 1937, vol. 18, Oct., pp. 423–433; Nov., pp. 487–492; Dec., pp. 542–552). The author discusses the determination of thermal efficiency and the drawing up of a heat balance for three typical industrial units: (1) A coal-fired boiler in which ashes and dust constitute the solid incombustible residues and in which the gaseous products of combustion contain carbon monoxide and hydrogen in addition to the other gases commonly found; (2) a boiler fired with blast-furnace gas in which no solid residues are produced. Special methods are used in this case to calculate the gas consumption; (3) a producer-gas-fired open-hearth furnace provided with a waste-heat boiler.

On the Determination of the Heat Loss due to Small Amounts of Unburnt Furnace Flue Gas, by means of the Calorimeter. W. Bühne. (Dissertation, Technische Hochschule zu Aachen, 1937). The author describes experiments to determine the thermal value of small amounts of unconsumed flue gas by means of the calorimeter. A synthetic flue gas simulating in composition gases occurring in practice was employed, and a detailed description is presented of the apparatus and technique used. Experimental differences in the values obtained amounted to $\pm$ 3·0%. The method is said to give more accurate results than methods for determining heat losses using gas-analysis apparatus of the Ados, Orsat and other types. Recording apparatus may be attached to the apparatus when this is used for technical-control purposes. Precautions to be observed in using the instrument are outlined.

The Radiographic Examination of Coal. R. Beeching. (Journal

of the Institute of Fuel, 1938, vol. 11, Feb., pp. 240–242). The results of experiments on the X-ray examination of coals treated with solutions of lead salts indicate that such treatment is likely to be of value in connection with the study of the breaking of coal. The lead salts penetrate into cracks and partings and render them readily discernible owing to the high opacity of the infiltrated material. Different types of absorption are discussed.

Ultimate Yield of Solvent Extraction of Coal. H. G. Landau and R. S. Asbury. (Industrial and Engineering Chemistry, 1938, vol. 30, Jan., p. 117). The authors discuss the calculation of the yield of extract for any solvent and any coal on extracting coal with organic solvents under pressure. An equation is derived which expresses the relationship between time and yield :

$$y = bt/(t + a)$$

where t = time, y = yield and a and b are constants. The equation applies only during the later stages of extraction.

The Bulk Density of Fine Coal. C. Koeppel. (Fuel in Science and Practice, 1938, vol. 17, Jan., pp. 10–18). An English translation of an article which appeared in Glückauf, 1937, vol. 73, Apr. 24, pp. 369–378. (*See* Journ. I and S.I., 1937, No. II., p. 58 A).

Coal Cleaning at the Parc Colliery. (Colliery Guardian, 1938, vol. 156, Jan. 28, pp. 155–156). An account is given of the new Chance washer installed at the Parc Colliery of the Ocean Coal Co., Ltd., South Wales. The plant is rated to handle 150–190 tons per hour of 6 in.–0 coal, a 10-ft. Chance cone being used. The operation of the machine is described in detail, and a flow diagram is given in the account.

Powdered Fuel Firing, a Means of Increasing the Output of Lancashire Boilers. T. F. Hurley and R. Cook. (Journal of the Institute of Fuel, 1938, vol. 11, Feb., pp. 195–208). It is demonstrated that although the large combustion chambers used when firing water-tube boilers with pulverised fuel are no longer necessary in order to secure good combustion, it is impracticable to reduce their size without encountering operating difficulties due to molten particles of ash being carried from the furnace by the flue gases. The fundamental reason for this limitation is the small ratio of surface to volume in large chambers. As, however, the ratio is large in the case of the Lancashire boiler the limitation disappears, and it should be possible to obtain large heat releases, limited only by combustion conditions, with this type of boiler. By the use of suitable methods for obtaining rapid ignition and controlled mixing of fuel and air reasonably good results may be obtained. Two burners are described which enable the required aims to be fulfilled. Test figures are given together with other data relating to boiler performance.

The Combustion of Anthracite Duff in Pulverised Form. J. Mayer. (Institute of Fuel : Colliery Guardian, 1938, vol. 156, Jan.

14, pp. 59–61; Jan. 21, pp. 110–113). After a brief account of the requirements of equipment for burning pulverised anthracite duff, the author describes the results obtained on two boilers at Cefn Coed Colliery each equipped for unit-type firing with different types of mills. Boiler No. 1 was fitted with a Raymond Lopulco mill, and boiler No. 2 was fitted with a Hardinge ball mill. General operating experiences, mill performance and service life are discussed. Experiences with anthracite-duff-fired boilers at the Tir John Power Station are also recorded. The bin-and-feeder type of firing method was employed, the fuel being supplied by four Hardinge ball mills each 10 ft. in dia. and 6 ft. long (parallel shell length). The fuels used at this plant are discussed at length, together with problems encountered with combustion. In both installations referred to official boiler tests were carried out. Graphical and tabular data are presented.

Pulverised Coal. (Nickel Bulletin, 1938, vol. 11, Feb., pp. 25–28). The advantages of using pulverised coal and the design and principle of the Atritor pulveriser are discussed. The use of " Atrinard " cast iron, a type of Ni-Hard cast iron, for the segments and pegs of the pulveriser is referred to. The ring main distribution system for firing metallurgical furnaces with pulverised coal is briefly described together with the Atritor boosting system in which chain-grate or retort-type stokers are retained in the system employed for firing a boiler but in which the pulveriser handles peak loads.

Internal Evacuation in the Coking Process. H. Niggemann. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Jan. 8, pp. 43–44). (*See* p. 6 A).

The Low-Temperature Coking of Coal-Oil Mixtures. A. Thau. (Glückauf, 1938, vol. 74, Feb. 5, pp. 97–104). The development of low-temperature carbonisation processes for bituminous coals in England and America evinces an increasing tendency to the use of mixtures of pulverised coal and oil. Plant operating on this principle is already in use in England. The Knowles oven and a modified type constructed in Russia are described, and brief descriptions of other methods depending on the use of pulverised-coal/oil mixtures are given.

The Recovery and Refining of Benzol in Coking Plants and Gas Works. C. Berthelot. (Génie Civil, 1938, vol. 112, Feb. 12, pp. 141–147). The author describes the development of processes for the separation of benzol from gas produced both in gas works and in coking plants. The principles of various systems for removing and refining the crude benzol are discussed and plants for eliminating carbon disulphide and for rectifying the material are examined at length. Reference is made to the use of active carbon.

Gas Desulphurisation with Recovery of Ammonia by the Method of the Gesellschaft für Kohlentechnik. H. Weittenhiller. (Glückauf, 1938, vol. 74, Feb. 12, pp. 126–131). The results of experiments on the commercial operation of the method of the Gesellschaft für

Kohlentechnik for desulphurising gas and recovering ammonia are described. The investigations were carried out on coke-oven gas. A full account is given of the plant at the Kokerei Kaiserstuhl 2, Dortmund, which was employed for the purpose. In the process the hydrocyanic acid is first removed and the hydrogen sulphide then absorbed by an ammoniacal suspension of ferric hydroxide, which is subsequently agitated with air to give sulphur. The ammonia is treated with sulphurous acid to give ammonium sulphite, and this in turn, on treatment with the sulphur recovered as above, gives ammonium thiosulphate, which yields ammonium sulphate and sulphur when treated with sulphuric acid. The advantages of the new method are discussed.

Investigations on a Blast-Furnace-Gas-Fired Steam Boiler to Test the Warranty Submitted. E. Senfter. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 307–313). The author describes tests carried out on a steam boiler fired with blast-furnace gas to determine the validity of warranties regarding its service and output supplied by the maker; these warranties are described. The operating conditions of the boiler are discussed, together with the testing methods employed. Sources of error possible in determinations by direct methods of the fuel consumption are examined at length and an indirect method is suggested and used for this purpose which is shown to be less liable to error. The evaluation of data obtained to demonstrate that the boiler fulfilled the warranties is dealt with in detail. Graphical and tabular data are presented.

U.S. Bureau of Mines Experimental Plant. H. H. Storch, L. L. Hirst, P. L. Golden, I. I. Pinkel, R. L. Boyer, J. R. Schaeffer, and R. H. Kallenberger. (Industrial and Engineering Chemistry, 1937, vol. 29, Dec., pp. 1377–1380). A description is given of an experimental plant for the continuous hydrogenation of about 100 lb. of coal per 24 hr. Major difficulties experienced in the operation of the plant and the solutions adopted are discussed. Typical results on the liquid-phase hydrogenation of Pittsburgh seam coal are given.

The Utilisation of Coal with Particular Reference to the Production of Oil. C. Legrand and M. Simonovitch. (Publications de l'Association des Ingénieurs de l'École des Mines de Mons, 1937 : Fuel in Science and Practice, 1938, vol. 17, Jan., pp. 4–10). The authors discuss the political and economic significance of supplies of natural petroleum and the importance of processes for producing synthetic liquid fuels to the chief European countries. Statistical data are presented.

PRODUCTION OF IRON

(Continued from pp. 178 A–179 A)

Blast-Furnace Control. E. G. James. (Iron and Steel Industry, 1938, vol. 11, Jan., pp. 127–129). The author presents an account of the electric drives for certain equipment forming an integral part of the blast-furnace, such as the skip hoist, distributor, depth-rod winch and bell hoists. Automatic contactor gear is preferable to hand control of these drives as, whilst each works intermittently, the maintenance of sequence in a well-defined cycle is essential. The main features of the controls are briefly outlined in each case.

Pig-Casting Machine. C. P. Clingerman. (Steel, 1938, vol. 102, Jan. 17, pp. 48–50). A description is given of the construction and operation of the double-strand pig-casting machine installed at the Carrie furnaces of the Carnegie-Illinois Steel Corp., Rankin, Pa. This machine produces 1500 tons of 80-lb. pigs in 24 hr., with a scrap loss of 7·4 tons per hr. in the same period. Four operators are required for the machine, the moulds of which are coated with "Maglikote" burnt dolomite and are preheated on the return side when starting the machine.

Steel Recuperators for Blast-Furnaces. Johannsen and Holschuh. (RTA, 1937, No. 40: Demag News, 1937, vol. 11, C, Dec., pp. 33–35). An account is given of the construction and operation of a steel recuperator attached to a large blast-furnace with an output of 500 tons of basic pig iron per day at the Röchling Iron and Steel Works, Völklingen, Saar. The characteristics of the brick stoves formerly used in conjunction with this furnace are compared with those of the new steel recuperator. Considerable economies in construction and operation are claimed.

Sodium Carbonate Treatment in Blast-Furnace Practice at the Röchling Iron and Steel Works. A. Holschuh. (Stahl und Eisen, 1938, vol. 58, Feb. 10, pp. 133–136). Experience in the production of low-manganese basic Bessemer pig iron at the Röchling Iron and Steel Works indicated the necessity for soda desulphurisation on a commercial scale. The use of molten soda was decided on, and resulted not only in excellent desulphurisation but also in lowered heat loss, less dusting and decreased loss of soda. The equipment for melting and handling the soda and the selection of suitable refractories are discussed. The desulphurised pig iron is rapidly and completely freed from slag in a special equipment.

Production of Basic Bessemer Pig in the Blast-Furnace with Acid-Slag Practice from Low-Grade German Ores. W. Lennings. (Stahl und Eisen, 1938, vol. 58, Jan. 13, pp. 25–34; Jan. 20, pp. 52–58: Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1938, vol. 6, Jan., pp. 1–24). Current prac-

tice for the smelting of rich iron ores in the presence of a high-lime slag is unsuitable for use with low-grade German ores owing to the large limestone additions required to balance the high silicon content of the ores and to the resultant increase in the amount of slag produced and the quantity of coke consumed. The acid smelting practice suggested by Paschke and Peetz has been investigated on an industrial scale and has proved applicable to these ores; only small additions of limestone are made, thereby reducing the quantity of slag formed and the amount of coke consumed to a minimum. The furnace efficiency, coke input and pig-iron output of normal practice and of the modified procedure employing an acid slag are contrasted. Whilst both the normal and modified practices are relatively more expensive when operating on low-grade ores than on rich ores, nevertheless the modified procedure involving the use of the acid slag enables the production efficiency of the furnace to be raised and thus indicates a method of reducing the cost of working German ores.

Fuel Consumption in Swedish Charcoal Blast-Furnaces. (Stahl und Eisen, 1938, vol. 58, Jan. 27, p. 85). A long abstract in German is presented of a paper by M. Wiberg which appeared originally in Jernkontorets Annaler, 1937, vol. 121, No. 7, pp. 355–454. The chemical reactions occurring during the reduction of iron ore in the charcoal blast-furnace are considered in detail together with the thermal characteristics of the furnace and data regarding fuel consumption and output. The fundamental knowledge obtained in the investigation described may be applied to considerations regarding the working of blast-furnaces operating on coke.

Production of Pig Iron by Electricity in the Norwegian "Spigerverk" Furnace. I. Hole. (Jernkontorets Annaler, 1937, vol. 121, No. 11, pp. 667–675). (In Swedish). The development of the Tysland-Hole furnace for the smelting of iron ore (referred to, on account of the collaboration afforded in its development by the Christiania Spigerverk, as the "Spigerverk" furnace) from the original Tysland furnace is described. The construction and operating details of the furnace are discussed at length. The layout of the furnace and auxiliary plant, raw materials employed in Norwegian practice, the metal, slag and gas production of the furnace, patching and fettling practice and brief references to Norwegian, Swedish, Italian and Finnish installations are presented.

Making Use of the Residues from the Production of Alumina. (Stahl und Eisen, 1938, vol. 58, Feb. 10, pp. 146–147). An abstract of an article by E. Herrmann which appeared originally in Chemiker Zeitung, 1937, vol. 61, pp. 493–496. Reference is made to the utilisation of waste products resulting from the preparation of alumina from bauxite as a source of iron. Tabular data are presented regarding the analyses of such wastes from different bauxites; the dry residue from the European type contains about 40–44% of iron, but difficulties entailed in smelting owing to the high

titanium dioxide content are noted. Reference is also made to the extraction of the titanium compounds. The preparation of the residues for smelting for iron is briefly outlined and other uses of the material are also indicated.

The De-Vecchis Method for Smelting Burnt Pyrites. (Usine, 1937, vol. 46, Jan. 28, pp. 29–33: Stahl und Eisen, 1938, vol. 58, Feb. 3, pp. 117–118). The De-Vecchis process for the smelting of pyrites entails the roasting and magnetic concentration of the raw material followed by reduction in a rotary kiln or electric furnace. The roasting process is peculiar in so far as instead of the reaction

$$4FeS_2 + 11O_2 = 2Fe_2O_3 + 8SO_2$$

taking place, the air supply is controlled and the magnetic oxide is reduced as follows in two or more steps:

$$3FeS_2 + 3O_2 = 3FeS + 3SO_2$$
$$3FeS + 5O_2 = Fe_3O_4 + 3SO_2$$

Pyrites may be directly treated or the burnt pyrites residues from other processes may be worked. By the use of certain chemical additions certain impurities in the raw material may be eliminated during roasting. The product may be briquetted and reduced in the blast-furnace, but is better smelted in an electric furnace. In France the process is of importance in connection with the production of sponge iron with a metal content of 80–85%, which is afterwards worked up into steel in the basic open-hearth or electric furnace; the production of the sponge and its subsequent treatment are discussed at some length.

Disruption of Iron Ore by Carbon Monoxide. W. Baukloh. (Stahl und Eisen, 1937, vol. 57, Dec. 23, pp. 1421–1423). The author discusses the theoretical bases of the separation of carbon from carbonaceous gases with reference to the equilibrium of the reaction $2CO \rightleftharpoons C + CO_2$. The conditions for the disruption of iron ore are defined. A series of illustrations is presented showing how a porous ore, such as minette, very rapidly crumbles, whilst a denser magnetite is only attacked by carbon monoxide from the surface inwards. It is also demonstrated that disruption can only proceed to the stage where the individual grains composing the ore become separated.

Relative Desulphurizing Powers of Blast-Furnace Slags. II. W. F. Holbrook. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 875: Metals Technology, 1938, vol. 5, Jan., No. 1). A continuation of previous work. (*See* Journ. I. and S.I., 1936, No. I., p. 211 A). The author extends his investigations to cover slags containing up to 20% of magnesia, and the effect of temperature on 5 and 15% magnesia slags from 1475° to 1525° C. is examined. A technique similar to that described in the previous report was employed, but some temperature measurements were made with a noble-metal thermocouple instead of the tungsten-

graphite couple. Desulphurising power is defined as the ratio of the percentage of sulphur found in the slag to that found in the metal. Six slag and metal charges were made simultaneously in $\frac{5}{8}$-in. holes in a section of an electrode graphite rod. One slag and metal charge was used as a control by means of which adjustment in the desulphurisation value could be made for small variations in the temperature and other factors. For convenient presentation of data, the slags are arranged in groups in each of which one of the four main slag components is constant.

The Siderurgical Industry in Czechoslovakia and its Relationship to the Scientific Organisation of Industry. J. Tille. (Mémoires de la Société des Ingénieurs Civils de France, 1937, vol. 90, July–Aug., pp. 515–529). The author describes the evolution of the Czechoslovakian siderurgical industry, its productive capacity and its commercial and economic organisation.

Anton Ritter von Kerpely (the Elder) and his Influence on the Development of the Hungarian Iron Industry and on the Metallurgy of Iron. E. Cotel. (Royal Hungarian Palatine-Joseph University of Technical and Economic Sciences, Publications of the Department of Mining and Metallurgy, 1937, vol. 9, pp. 68–76). Reference is made to early investigations (by von Kerpely) on the chemical composition of Hungarian iron ores, on the relationship between the chemical composition and the hardness of iron (originating in a study of the wear of railroad track), on the determination of hardness by the "electromagnetic" method, and other work on the metallurgy and practical applications of iron and steel.

The Shortage of Raw Materials as Regards Ore and Iron. H. Leobner. (Montanistische Rundschau, 1938, vol. 30, Feb. 16). The author discusses the shortage of iron in States not possessing adequate domestic ore resources. The working up of old slag and dumped ore is referred to, together with the investigation of new methods of dressing and concentration which have apparently enabled the iron content of some naturally occurring minerals to be increased from 12% up to 40–50%. Various methods of utilising different types of scrap are considered. Special attention is devoted to the problems involved in the recovery of the metal scrap from reinforced concrete, and reference is made to efforts in this direction undertaken by the Japanese forces in China. Various methods are suggested for separating the reinforcement from the concrete, whilst it is proposed that smaller masses of masonry from which it would not be possible or profitable to separate the metal might be smelted down to give an easily fusible slag from which the iron might be recovered by normal metallurgical processes.

FOUNDRY PRACTICE

(Continued from pp. 180 A–183 A)

Cupola Practice. S. E. Dawson. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Jan. 27, pp. 97–98, 100). The author discusses the design and operation of the cupola. The height of the tuyeres, the dimensions of the blast main and wind belt, the size and disposition of tuyeres, linings, the depth and weight of the charge, the air-to-coke ratio and the influence of cupola practice on the metal are discussed. Reference is made to experiments on the remelting of pig iron to determine the degree of persistence of the original characteristics of the iron and to the grain and graphite-refining effects of carbon dioxide in the presence of small amounts of titanium.

Electrically-Melted High-Duty Iron. V. A. Crosby. (Foundry Trade Journal, 1938, vol. 58, Jan. 27, pp. 103–105). A discussion on MacDougall's paper on high-duty cast iron (*see* p. 117 A). The comparative effects of nickel and molybdenum on the tensile strength of cast iron are considered in relation to melting practice and to the microstructures of the metal. Tabular data and micrographs of typical irons are presented to support the view that progressive improvements in the tensile properties of cast iron result from increasing additions of molybdenum.

Faster Annealing of Malleable Cast Iron. J. T. Bryce and H. G. Schwab. (Metal Progress, 1938, vol. 33, Jan., pp. 35–41). The authors discuss initially the value of duplexing and of re-adjusting the carbon-silicon ratio in cast irons intended for the production of blackheart malleable castings, particularly in regard to the opportunity which such procedures give for shortening the annealing time. The introduction of improved annealing methods is then dealt with in detail; shortened annealing cycles, the use of improved furnaces (including car-bottom continuous-type kilns) and the use of the controlled-atmosphere furnace with radiant-tube heating elements are considered, the methods of producing the required atmosphere being described. Special reference is made to the difficulties experienced in maintaining a controlled atmosphere of the correct composition owing to the fact that the white iron itself evolves carbonaceous gases during the annealing process and that the relative percentage of carbon- and non-carbon-bearing constituents in the atmosphere must be varied as annealing proceeds in order to effect the surface reactions necessary to yield a product of the desired type; the necessity of avoiding surface carburisation is stressed. Continuous and batch-type furnaces utilising controlled atmospheres are then described, structural and operating data being given. The respective applications and merits of each of these types of furnace are examined in conclusion.

The Acid-Lined Arc Furnace for the Production of Steel Castings. R. van Tongel, sen. (Stahl und Eisen, 1938, vol. 58, Jan. 27, pp. 83–84). Experiences at the Van Tongelschen Stahlwerken, Güstrow, Mecklinburg, have demonstrated that steel castings may be produced from metal melted in the acid-lined arc furnace without difficulty; the cost of melting is less than that entailed in the basic-lined furnace. In spite of the viscous slag melting is steady and uniform if the current supply is suitable, while since the melting rate is faster, the output may be correspondingly raised. The charge may be superheated at will and may be cast into the smallest mould; phosphorus and sulphur may be held readily to 0·03% each. Furthermore, the steel is thoroughly deoxidised and there is little danger of flaws. The service life and construction of the furnace are superior to those of the basic-lined furnace. These conclusions apply only to furnaces of relatively low capacity and to those engaged in melting steel containing more than 0·15% of carbon.

Production and Properties of Steel Castings. F. Cousans. (Institution of Mechanical Engineers: Foundry Trade Journal, 1938, vol. 58, Feb. 10, pp. 145–148, 150). The author describes mould- and core-making practice for the production of steel castings, special problems entailed by the contraction of the solidifying metal, the pouring of molten steel, stripping, the properties of plain carbon, carbon-manganese, nickel-manganese, nickel-chromium, nickel-chromium-molybdenum, carbon-molybdenum and manganese-molybdenum cast steels, and austenitic manganese-steel castings; the designing and machining of the last type of castings are given detailed treatment. Data are given in tabular form.

Testing of Moulding Sands. N. D. Ridsdale. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Jan. 20, p. 81). The apparatus and technique for testing moulding sands are briefly discussed. Moisture content, bond strength and clay determination are dealt with.

Controls Moulding Sand Properties. W. G. Reichert. (New England Regional Foundry Conference: Foundry, 1938, vol. 66, Jan., pp. 33–34, 76, 79). The author discusses the fundamental properties of a sand which make it suitable for moulding purposes. Permeability, green and dry strength, fineness of grain and compacting properties are considered, together with means of determining and controlling these values. The relationship between the properties of the moulding sand and the behaviour of the mould and the quality of the finished casting are also discussed.

Loam Moulding of a Hydraulic Ram. A. Greenhalgh. (Foundry Trade Journal, 1938, vol. 58, Jan. 6, p. 11). A description is given of the making of a loam mould and core for a hydraulic ram 4 ft. in dia. and 4 ft. 6 in. deep.

Results of Economic Investigations in Loam-Moulding Shops and their Application to Managerial Practice. C. Bäume. (Dissertation, Technische Hochschule zu Aachen, 1937). The author conducts and analyses time studies of individual operations in a

loam-moulding shop, and suggests a scheme of shop organisation based on his findings. Rate fixing is also discussed.

Production of Flange Pipe Templets or Closures. (Foundry Trade Journal, 1938, vol. 58, Jan. 27, pp. 99–100). The difficulties encountered in the designing and production of flange pipe templets are briefly discussed, reference being made in particular to the casting of two bore closures, 12 in. and 30 in. in dia., respectively. The use of measurements and drawings is considered preferable for numerous reasons to that of templets, which are both expensive and do not necessarily indicate fully the shape of the article to be produced. In addition they are liable to be damaged in use and transit.

Foundry Mechanisation. Some Considerations on Continuous-Casting Plants. A. Wynn. (Foundry Trade Journal, 1938, vol. 58, Jan. 13, pp. 31–32). The author considers problems encountered in the mechanisation of a foundry. The selection of sites and choice of layout are dealt with, together with increased life and decreased maintenance costs on the part of mechanised units and drives due to improved designs. The safety and welfare of operatives are also discussed in relation to mechanisation.

The Works of John Harper (Meehanite), Limited. (Foundry Trade Journal, 1938, vol. 58, Feb. 17, pp. 163–164). An account is given of the foundry of John Harper, Ltd., Albion Works, Willenhall. The melting plant, sand-preparing equipment, moulding practice and fettling department are described and a brief reference is made to the mechanical properties of Meehanite cast iron.

The Mechanised Foundry at the Witton Works of the General Electric Company, Ltd. (Engineering, 1938, vol. 145, Jan. 28, pp. 100–101). A description is given of the moulding equipment at the foundry of the Witton Works of the General Electric Co., Ltd. It comprises five pairs of moulding machines in each of two units, ten sand hoppers, a mould conveyor and sand-preparation plant and a knock-out station. The operating cycle involved in moulding is briefly described.

Expert Technique Needed for Quality Castings. P. Dwyer. (Foundry, 1938, vol. 66, Jan., pp. 24–27, 68, 70). An account is given of the plant and plant layout of the Fulton Foundry and Machine Co., Cleveland, Ohio, for the production of Meehanite cast iron. Some reference is made to the mechanical properties of different grades of iron produced.

Exhaust Requirements for Foundry Dust Control. J. M. Kane. (Foundry, 1938, vol. 66, Jan., pp. 30–32, 74). The author discusses the provision of dust-extracting or exhausting equipment for various foundry units, such as shake-outs, sand screens or conditioning equipment. The design and attachment of hoods and ducts are considered. It is indicated by the Engineering Committee of the Dust Control Equipment Association that data presented by the author must be used as a guide to average requirements only and, when necessary, should be modified to suit the conditions prevailing.

Time and Motion Studies in the Foundry. C. D. Pollard. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Jan. 20, pp. 87–88; Jan. 27, pp. 101–102, 108; Feb. 3, pp. 118–120; Feb. 10, pp. 140–141, 144). The author discusses the value of time and motion studies as aids to production in the foundry, to costing and to rate-fixing. Specimen study cards, operation cards and time cards are illustrated and the processes by which the data contained on them were arrived at are discussed and analysed.

Design in Relationship to Contraction and Distortion. E. Longden. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Feb. 3, pp. 115–118). The author considers the relationship between design and contraction and distortion in connection with heavy and relatively complicated castings; in particular the fracture of each half of a heavy-duty planing machine table weighing about 35 tons is dealt with. Contraction phenomena in test bars and in the machine bed referred to are examined, and it is demonstrated how the contraction of large castings is influenced by design. The new and old designs for the planing machine bed are compared.

This Fluidity. J. H. Pearce. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Jan. 6, p. 7). The author discusses the definition of "fluidity" as applied to a molten metal, describes briefly methods of determining it and deals at some length with composition, temperature and method of manufacture as factors of prime importance in their influence upon fluidity.

Contribution on the Determination of the Running Properties of Liquid Metals. W. Ruff. (Zeitschrift für Metallkunde, 1937, vol. 29, July, pp. 238–241). This paper is based upon work carried out with the aid of a grant from the Andrew Carnegie Research Fund of the Iron and Steel Institute and published originally in English in the Carnegie Scholarship Memoirs of the Iron and Steel Institute, 1936, vol. 25, pp. 1–39, but certain data are included in the German version that were not recorded in the English account, which, in turn, contains some additional matter not reproduced in the German text.

PRODUCTION OF STEEL

(Continued from pp. 184 A–187 A)

Operating Characteristics of New Open-Hearth Furnace. C. Longenecker. (Blast Furnace and Steel Plant, 1937, vol. 25, Dec., pp. 1279–1281). An account is given of the operation of a new open-hearth furnace at the Hamilton Plant of the Steel Company of Canada, Ltd. The furnace operates with a non-luminous flame according to the McKune system and under automatic control. Coke-oven gas, blast-furnace gas, fuel oil and producer-gas can be utilised as fuel, but it is intended to use only the first two. Combustion occurs in the central port. The classification of heats, furnace charges, controls, utilisation of waste gases in a waste-heat boiler and fuel consumption are dealt with. The fuel consumption averages 2,904,000 B.Th.U. per net ton of ingots produced.

The Auto-Charged Electrically Operated Mobile Charging Machine. (Iron and Coal Trades Review, 1938, vol. 136, Jan. 14, p. 39). The construction and operating mechanism of two mobile charging machines actuated electrically by current taken through a trailing cable are described. The types referred to are for charging open-hearth furnaces and reheating furnaces.

On the Significance of Chemical Equilibrium in the Production of a Steel with Low Slag Content and of Uniform Composition. C. Benedicks. (Metallwirtschaft, 1938, vol. 17, Jan. 21, pp. 59–60). In order that the metallic phase of a given ternary system (*i.e.*, melt deoxidising agent and a non-metal such as oxygen) may be as free as possible from admixture with the slag phase it is essential that heterogeneous chemical equilibrium should prevail in the system before pouring. To economise in both time and material it is possible deliberately to adjust the composition of the phases in the direction of equilibrium. Polyphase systems may be considered in the same light only when similar discontinuities in miscibility are present.

Research on the Physical Chemistry of Metal/Slag Reactions. F. Körber. (Zeitschrift für Elektrochemie, 1937, vol. 43, July, pp. 450–460). The author describes the purposes served by slag coverings in various metallurgical processes and indicates the various ways in which the reactions between the slag and the molten metal may be investigated with a view to obtaining results of a practical nature. The conditions required in laboratory investigations of metal/slag reactions and the evaluation and presentation of the results are discussed. The equilibria between mixtures of two metals and mixtures of their halogen salts or silicates are discussed. The technically important equilibria of reactions between molten iron, iron-manganese silicates and solid silica are then dealt with in detail. The value of detailed research is considered and illustrated by

reference to the reactions occurring in acid processes for the production of steel and to reactions taking place during the deoxidation with manganese and silicon of steels containing oxides. Finally the scope of further research is indicated, part of which is already being undertaken, as, for example, the metallurgical behaviour of alloying elements in steels and of non-metallic impurities, particularly sulphides.

Systematic Study of Metallurgical Processes with Special Consideration of the Part Played by Gases. R. Schenck. (Zeitschrift für Elektrochemie, 1937, vol. 43, July, pp. 438–450). The author reviews, *inter alia*, the results of researches upon the equilibria of the iron-carbon, iron-manganese-carbon and chromium-carbon systems and also upon the equilibria of the chromium-nitrogen and manganese-nitrogen systems. The physical chemistry of carbon monoxide is discussed with reference to equilibria in reactions between metallic oxides and elementary carbon; more particularly, the reactions between iron and carbon monoxide and ferrous oxide and carbon monoxide are considered.

The Process of the Dephosphorisation of Steel in the Basic Process. K. Richter. (Montanistische Rundschau, 1938, vol. 30, Feb. 16, pp. 6–7). The author describes in detail experiments carried out on melts in a 16-ton basic open-hearth furnace to determine the course of the dephosphorisation of the charge. Analyses are presented of the phosphorus contents of the materials comprising the charge, the finished steel and the slag both during the melting process and at its completion. Data are presented in graphical and tabular form.

On the Desulphurisation of Iron. J. Milej. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., No. 3–4, pp. 106–111). (In Polish). The author considers first the theory of the desulphurisation of iron containing small amounts of slag. The reactions and equilibria between the slag and iron melt are presented in the form of a series of equations which indicate that by the continued addition and removal of small amounts of slag the equilibrium of the reaction is shifted constantly to the right, the final concentration of sulphur in the melt being reduced therefore, if necessary, to a very low value. It is also shown that from one equation in this series the theoretical minimum addition of slag may be calculated if it is assumed that this slag will not become saturated with sulphur. The author then passes on to a consideration of the influence of manganese. A further series of equations is presented showing that the amount of slag required to effect desulphurisation is conditioned by the manganese concentration in the iron melt. It is shown that the influence of the manganese becomes proportionately greater as the conditions for desulphurisation by lime become more unfavourable (high concentration of acid constituents and ferric oxide in the slag). When the slag is well deoxidised, manganese, even in heavy concentrations, exerts hardly any effect on the desulphurising process.

Killed and Effervescing Steels. L. Guillet. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Sept., pp. 493–512; Oct., pp. 545–563; Nov., pp. 597–613; Dec., pp. 657–664). The replies are presented to a questionnaire addressed to a number of manufacturing and scientific bodies and individuals concerning the definition of killed, semi-killed and effervescing steels and the considerations on the basis of which a steel is assigned to any given class; whether each may be manufactured at will in the open-hearth or electric furnace; the differences between the operations involved in the preparation of each type of steel, particularly with respect to additions; the differences in properties between the three types of steel for any given grade of material; the possibility of some relationship existing between the grain size of the steel and the three different forms of the particular grade of steel in question; the reactions of each type to mechanical shock, to stamping and to welding and rimming; the possibility of controlling the position of the blow-holes in rimming steel.

Production of Common Quality Basic Billets from the Electric Furnace. A. G. Robiette. (Iron and Steel Industry, 1938, vol. 11, Jan., pp. 119–121). The author discusses the production of common quality basic steel in the arc furnace. The changes in furnace design which have made this an economical process are discussed, operating practice for the production of basic steel in this way is outlined and operating costs are analysed.

The Refining of Steel in the Coreless Induction Furnace. V. Stobie. (Stahl und Eisen, 1938, vol. 58, Feb. 10, p. 446). The author describes a specially-designed coreless induction furnace for steel refining and points out the reasons for difficulties encountered in the use of furnaces of normal design for this purpose. The lining of the furnace is discussed and the results are given of experimental runs, with special reference to the removal of non-metallic impurities from the charge during melting.

REHEATING FURNACES

(Continued from p. 123 A)

Studies of Regenerative and Recuperative Furnaces. W. A. Morton. (Iron and Steel Engineer, 1938, vol. 15, Jan., pp. 24–34). The author describes a producer-gas-fired regenerative furnace for glass with hearth dimensions of 25 ft. × 65 ft. × 4 ft. deep; it is noted that such a furnace would hold 3480 tons of molten steel. Full details are given of the construction, lining and operation of this furnace. A typical reversing regenerative furnace for ingot heating is described and its unsound design commented upon; it is compared with a new design of regenerative ingot-heating furnace in which such weaknesses are eliminated. A full description is given of the Amco non-reversing pit furnace for ingot heating. It is provided with a recuperator and operates on blast-furnace gas; the thermal characteristics and output capacity of the furnace are discussed in detail, and the developments which have taken place in the construction of the Amco type of furnace are dealt with at length, particularly in regard to recuperator design. Tabulated operating data are given for a coke-oven-gas-fired pit furnace of this type. Details are also presented of the design proposed for a non-reversing recuperative open-hearth furnace of 50–75 tons capacity in which the firing is continuous from one end of the hearth to the other; the advantages of the new design are enumerated. Reference is made to the benefits of the automatic control of furnaces and to the relative merits of regenerative and recuperative furnaces.

Controlled Ingot Heating. W. A. Morton. (Steel, 1937, vol. 101, Dec. 13, pp. 44–48, 80). The author describes the Amco pit furnace. (*See also* Journ. I. and S.I., 1937, No. II., p. 223 A).

Progress in Steel Plant Furnaces. (Industrial Heating, 1938, vol. 5, Jan., pp. 31–52). The essential features of and improvements effected in the latest furnaces for steel plants are considered at length; the discussion covers improvements in construction, operation and thermal efficiency, while the increased adaptability of many types is emphasised. The furnaces dealt with include those for ingot heating, for the treatment of sheet and strip, pipes and tubes, for rods and wire products, for heating bars and billets, and other types such as bell- and convection-type annealing furnaces.

Furnace Practices Improve Forgings. L. E. Raymond. (Metal Progress, 1937, vol. 32, Oct., pp. 373–376). The author describes the solutions of difficulties experienced with unsatisfactory forgings by the installation of an oil-fired furnace with automatic temperature control, and its subsequent replacement by a furnace fitted with the so-called "luminous flame" burners and also provided

with an automatic temperature controlling and recording device. The improved nature of the materials produced is noted.

Furnaces with Controlled Atmospheres Used for Forging Fine Steels. A. M. Steever. (American Gas Association, Sept.–Oct., 1937 : Industrial Heating, 1937, vol. 4, Nov., pp. 976–979). The author considers the development of the controlled-atmosphere furnace. Constructional details are presented respecting the conversion of a gas-fired furnace of the ordinary type to the controlled-atmosphere type. Newer furnaces embody the principles first laid down by experiments on converted furnaces of this type. The construction and operation of the controlled-atmosphere furnace are outlined.

Heating Slabs. (Steel, 1938, vol. 102, Jan. 31, pp. 54–56). An account is given of three continuous slab-heating furnaces serving the new continuous sheet and strip mill of the Jones and Laughlin Steel Corporation, Pittsburgh. They are of the triple-fired, zone-controlled type. Each is rated at 50 tons (gross) of cold slabs per hour, while zone firing enables efficient operating conditions to be maintained with various throughputs. The effective length of the furnaces is 80 ft., while the width is 18 ft. Coke gas or tar is used as fuel. The construction and characteristics of the furnaces, which are of the Rust type, are discussed at length.

Direct Electric Resistance Heating of Steel for Forging, Upsetting, etc. F. P. Peters. (Metals and Alloys, 1937, vol. 8, Oct., pp. 281–287). The author considers the practical requirements of a heating process in connection with forging and deals with equipment fulfilling such requirements. Among the methods of heating discussed the two satisfying most of the ideal requirements are considered to be high-frequency induction heating and direct resistance heating; the latter is examined in detail. Among the advantages noted are the short heating time required, the certainty of obtaining the core of the material at least as hot as the outside, and the avoidance of scaling, burning and grain growth. Included in the account are typical applications of the direct-resistance heating process for both upset-forging and heat-treatment purposes, references to the construction and mode of operation of the Berwick rivet heater and electric forging heater, and instances are cited from practice of the performance in service of machines of this class.

FORGING, STAMPING AND DRAWING

(Continued from pp. 188 A–189 A)

Time Standards for the Drop Forge Die Shop. Part II. Punches. C. N. Harwood. (Heat Treating and Forging, 1937, vol. 23, Dec., pp. 604–609). A continuation of a previous article (*see* p. 188 A). The application of time studies to tool-room operations involved in the making of punches is described. The details of the machining and allied operations are discussed and the results of time studies in respect to these are subjected to a detailed analysis. Tabular data are presented.

Developments in Presses and Sheet-Metal Machinery Go on Apace. F. J. Oliver. (Iron Age, 1938, vol. 141, Jan. 27, pp. 28–33). The author describes some recent designs of sheet-metal presses. A single-action press with a hydro-pneumatic cushion for carrying out operations previously requiring a double-acting press, a high-speed hydraulic press, two types of welded steel bending presses, a seven-stage hydraulic drawing press, turret-head punches and a nibbling press are among the machines dealt with.

Wire Drawing. F. C. Thompson. (Midland Metallurgical Societies: Wire Industry, 1937, vol. 4, Nov., pp. 611–613; Dec. pp. 647–651). The author discusses the power requirements for the drawing of metal into wires through dies from the mathematical standpoint, and analyses the results obtained from investigations upon wire-drawing operations carried out at high speeds. The influence of the speed of drawing and the significance of the elastic limit and of the reduction of area effected by the pass are dealt with. The effects of the angle and contour of the die are also considered, together with " casting," problems of lubrication and various lubricants, the effect of rotating the die, the effect of a backward pull while the material is passing through the die, and the "Alkins " effect. The Hele-Shaw apparatus for the investigation of the flow of metals is also briefly referred to.

Spring Wire Production. R. Saxton. (Wire Industry, 1938, vol. 5, Jan., pp. 31–33). The author discusses the types and applications of springs and spring wire. For upholstery work a 0·25% carbon, basic-Bessemer steel is widely used; other spring wire for the same industry is made of 0·5% carbon basic steel, while material containing up to 0·75% of carbon also finds some use. The working-up of the wire rod for springs is briefly described. Spring wire for engineering purposes and for instruments is also dealt with; reference is made to the use of 2% silicon, 1% manganese steel for springs subjected to severe fatigue conditions, and to the use of 18/8 stainless steel for springs exposed to strong corrosive influences.

ROLLING-MILL PRACTICE

(Continued from pp. 190 A–191 A)

Stressing, Wear and Grinding of Rolls for the Production of Heavy and Light Plates and Sheets. O. Emicke. (Stahl und Eisen, 1938, vol. 58, Jan. 27, pp. 73–82; Feb. 3, pp. 112–117; Feb. 10, pp. 136–145). In the first part of this article the author considers the following aspects in connection with materials of which rolls are made and with the stresses to which rolls are subjected : Classification of non-alloy iron and steel rolls for plate rolling, methods of selecting rolls for a given purpose, roll stresses due to alternating loads and thermal effects and the cause of breakages, the configuration of the gap between the rolls when in operation, means for maintaining rolls in good condition and for ensuring stability, and the calculation of strains due to bending stresses. In the second part of the article the wear of rolls is discussed and variations in weight and thickness of the rolled products are considered in relationship to means of determining when rolls require to be changed. Variations in the thickness of cold- and hot-rolled sheet are also dealt with, together with problems in connection with the regrinding and changing of rolls. The wear-resistance of chilled rolls and the effect of alloy additions upon this property are examined at some length. In the concluding part, the grinding of rolls is dealt with; grinding wheels are discussed in detail, together with requirements of the roll-grinding machine, wheel dressing with diamond dressings, checking the accuracy of grinding with gauges and the setting-up of roll-grinding machines.

Properties and Uses of Lubricating Greases. S. Ballard. (Steel, 1938, vol. 102, Jan. 10, pp. 36–40). The chemical and physical properties of greases are considered and their special applications as lubricants discussed. Lime-soap and mixed-base greases are dealt with and graphite and extreme-pressure lubricants are briefly examined. Reference is made to problems encountered in the separation of soap deposits, to the use of soft greases and to factors other than those already mentioned which affect the applicability of a grease to any particular purpose.

Modern Rolling-Mill Design. A. Poole. (Proceedings of the Institution of Mechanical Engineers, 1937, vol. 136, pp. 353–371). After surveying the various types of hot rolling mill for heavy ingots and their evolution, the author describes certain examples exhibiting novel features in design. The adaptation of a modern heavy mill manipulator to an existing blooming mill, the incorporation of fabricated structures in place of steel castings for mill tables, small hand-worked mills for the accurate finishing of high-grade steels in

small bar sizes, a modern high-production four-strand continuous wire-rod mill plant and examples of recent designs in rolling-mill auxiliary equipment are dealt with. The question of roll-neck bearings is discussed and a special bronze-and-white-metal combination roll-neck bearing is described.

Recently Completed Modernization at Wisconsin Steel Works. (Iron and Steel Engineer, 1938, vol. 15, Jan., Supplement, pp. 66–69). An account is given of the growth of the Wisconsin Steel Works and of the new reversing blooming and continuous mill. The new plant is installed in the enlarged main mill building, which is now 800 ft. long; it comprises a 40-in. blooming mill, bloom-crop shear, a 32-in. blooming mill, a billet and slab shear, two transfers, a 6-stand 21-in. continuous mill, flying shear, finishing end tables, shear and cooling beds. The layout of the plant is described and a detailed account is given of the mill drives and of the construction of the mills themselves. Some data are given respecting the output of the works now that the new units have been completed.

Special Stand for a 37-in. Two-High Reversing Mill. (Demag News, 1937, vol. 11, C, Dec., pp. 25–27). An English translation of an article by F. Münker which appeared originally in Stahl und Eisen, 1937, vol. 57, Dec. 30, pp. 1447–1449. (*See* p. 190 A).

A Look at the Three-High Sheet Mill. (Iron and Steel Engineer, 1938, vol. 15, Jan., pp. 70–74). The evolution of the modern three-high mill is briefly outlined and an account is then given of the mechanised electrically-controlled "jump" and "balanced" types, the former being characterised by the drive being connected to the bottom roll only, whilst the latter has both top and bottom rolls driven. The characteristics of each type of mill are discussed. The use of the Lewis mill (or "jump" mill) for sheet rolling is dealt with and reference is made to installations already in use in the United States and other countries. The behaviour of the new three-high mill in practice is compared with that of older types of mill. The special problems encountered in the selection of a suitable material for the rolls of three-high mills are noted; a special type of iron productive of a high finish on the sheet and giving improved service life is said to have been developed.

Jones and Laughlin Now a Producer of Strip. (Blast-Furnace and Steel Plant, 1937, vol. 25, Dec., pp. 1305–1312). An account is given of the plant and operation of the new 96-in. strip mill at the Pittsburgh Works of Jones and Laughlin. (*See* p. 191 A).

Electric Drives and the Steel Industry. (Metallurgia, 1938, vol. 17, Jan., pp. 79–81). Brief descriptions are given of the construction and mode of operation of control gear for electrically operated rolling-mill and rolling-mill auxiliary plant drives. Some recently installed rolling-mill drives are also dealt with, including equipment for the South Durham Steel and Iron Co., Ltd., the Shelton Iron, Steel and Coal Co., Ltd., and the Cleveland Works of Messrs. Dorman, Long and Co., Ltd.

PYROMETRY

(Continued from p. 65 A)

The Measurement of Temperature by Means of the Thermocouple and Galvanometer. H. De Rycker. (Revue Universelle des Mines, 1937, vol. 80, Dec., Chronique de l'Association des Ingénieurs sortis de l'École de Liége, pp. C32–C36). The author discusses the construction of thermo-electric pyrometers and of the indicating equipment used in conjunction with them. The sources of errors in both couple and galvanometer are considered.

Pyrometry and the Steel Makers' Refractories. R. B. Sosman. (Journal of the American Ceramic Society, 1938, vol. 21, Feb., pp. 37–49). The author discusses the use of pyrometers in steel-making plant. Various types of pyrometers and the special applications of each are considered, while the reactions of different refractories to high temperatures are considered at some length.

Temperature Measurements During the Preparation of Metallographic Sections. G. Kritzler. (Giesserei, 1938, vol. 25, Jan. 14, pp. 2–6). The author describes a technique and apparatus (platinum/platinum-rhodium thermocouples and millivoltmetres) for determining the temperatures and temperature gradients in test-pieces during grinding and polishing operations. Experiments were carried out on steel St.50.11, on 0·93% carbon steel and on whiteheart and blackheart malleable iron castings. In the case of the eutectoid steel structural alterations could usually be observed only after relatively prolonged exposure to high temperatures. In all cases, however, the effects of temperature are remarkably appreciable considering the comparatively short duration of heating. Finish grinding by hand and polishing were not sufficient to remove the altered surface. When examining the materials experimented upon and other specimens liable to undergo surface alterations if heated above a certain temperature, grinding on abrasive wheels should be dispensed with and a method should be adopted in which a temperature increase is avoided. Alternatively, grinding must be carried out under water or in conjunction with very effective cooling agents. The minimum pressure should be employed in order that the cooling liquid may pass between the surface of the specimen and the abrasive surface.

A Suction Pyrometer for the Determination of Gas Temperatures up to 2000° F. E. A. C. Chamberlain. (Journal of the Society of Chemical Industry, 1937, vol. 56, Oct., pp. 395T–396T). A suction pyrometer for measuring gas temperatures up to 2000° F. is described and the advantages claimed for it are enumerated.

HEAT TREATMENT

(Continued from pp. 192 A–197 A)

Plow Shares. C. A. Anderson. (Steel, 1938, vol. 102, Jan. 24, pp. 62–63). An account is given of the carburising practice at the Moline Plant (Illinois) of the Minneapolis-Moline Power Implement Co. The Company producees plough shares and mould boards in 0·10–0·20% carbon steel containing 0·70–1·0% of manganese (SAE X-1015); the material is carburised in plate form, this operation involving a somewhat unusual handling and packing procedure which is described in detail. Muffle-type furnaces fired with natural gas and provided each with eight staggered burners above and below the charge to ensure uniform heating are employed. The temperature is automatically controlled to within about 10° of 1700° F., and the material remains in the furnace for 22–26 hr., after which it is quenched down to 900° F., placed in an annealing furnace and brought up to 1350° F. in about 1 hr., soaked at this temperature for about 1·5 hr. and then rolled flat while it is still hot. The case depth on either side is equal to about one-third of the thickness of the metal, the core being soft and tough. Subsequent forging, welding and hardening operations are dealt with in conclusion.

The Blowpipe as a Means of Heating. (Soudeur-Coupeur, 1937, vol. 16, Dec., pp. 1–8). An account is given of the use of the oxy-acetylene torch for heating sheet metal to facilitate flattening, bending, flanging and allied operations. In particular, operations of this type in automobile repair shops are referred to.

Crankshafts and Other Parts Surface Hardened by Inductive Heat. E. F. Cone. (Metals and Alloys, 1938, vol. 9, Jan., pp. 1–6). The development and principles of the " Tocco " surface-hardening process, which involves the local surface heating of the part to be hardened by induced currents from a primary circuit supplied with current at a frequency of 2 kilocycles, are described in connection with the application of the process to the hardening of steel crankshaft bearings by the Ohio Crankshaft Co., Cleveland. Some account is given of the types of steel treated, the quenching procedures, characteristics of core and case and the subsequent processing of the hardened surface. It is noted that the control of all important factors in this method of heat treatment is fully automatic. The hardness obtained at the surface is about Rockwell 60 C or 600 Brinell.

Heat-Treatment Furnaces. (Metallurgia, 1938, vol. 17, Jan., pp. 105–106). A brief description is given of the " Liptak " air-jacketed heat-treatment and forging furnace, which is claimed to be free from the disadvantages which result in low thermal efficiency in many other types of furnace; two causes of low thermal efficiency

are discussed. The furnace is constructed on the suspended arch and wall principle and is encased in a thin outer jacket of insulating material from which the refractories proper are separated by an air space. The thermal characteristics of the furnace are discussed at length.

Better Control of Heat-Treating and Other Processes Given by New Instruments. F. J. Oliver. (Iron Age, 1938, vol. 141, Feb. 3, pp. 48–53). Developments in pyrometers and other temperature measuring and controlling devices of the indicating and recording types are reviewed. Three throttle-type furnace controllers operating on the potentiometric principle are described, together with new designs of portable recording pyrometers. Among other equipment described are precision optical pyrometers, a reversing cycle timer for soaking pits and open-hearth furnaces, and a small gas-fired tool-room furnace. A concluding section of the article deals with electrical controls of various kinds for motors and other industrial units operated by electricity.

Mass Effect in Some Alloy Steels. R. H. Greaves and S. H. Rees. (Metallurgist, 1938, vol. 11, Feb., pp. 103–108). The authors have investigated the effect of mass on the results of the heat treatment of five alloy steels comprising a carbon steel containing 0·5–1·0% of nickel, a steel containing 1·2% of nickel and 0·4% of chromium, a steel containing 1·2% of chromium and 0·24% of vanadium, a steel containing 1·2% of chromium and 0·26% of molybdenum and a steel with 1·4% of manganese and 0·32% of molybdenum. The low-nickel steel in sizes over 2 in. square could only be toughened by oil-quenching, while in sizes above 4 in. square its Brinell hardness when so treated did not exceed 220. The low nickel-chromium and the chromium-vanadium steels gave tensile strengths of 50 tons in 3-in. bars, but at this size both the yield point and impact values showed appreciably the influence of mass. In the chromium-vanadium steel there was a marked difference in properties between the centre and the outside of bars 4½ in. in dia. The beneficial effect of molybdenum is shown by the uniformity in properties from centre to circumference of 6-in. dia. bars containing this element. The authors draw important conclusions as to the optimum quantity of alloy additions which may be made to steels for various purposes.

The Application of Protective Atmospheres to the Bright Annealing of Steel Sheets and Strip. A. G. Robiette. (Swansea Technical College Metallurgical Society, Dec. 4, 1937). After a preliminary discussion on the development of the bright-annealing process and its advantages the author passes on to a consideration of chemical factors, the types, production and regeneration of protective atmospheres, the influence of residual lubricants on the sheet and strip, problems in connection with decarburisation, the use of controlled atmospheres for descaling, and types of furnaces and applications of the process.

WELDING AND CUTTING

(Continued from pp. 198 A–200 A)

Welding and Fabricating. W. Spraragen. (Iron Age, 1938, vol. 141, Jan. 6, pp. 445–453). **Welding Marches On.** W. Spraragen. (Iron Age, 1938, vol. 141, Jan. 20, pp. 28–29; Feb. 3, pp. 42–46). The author presents a review of the development of welding technique in 1937 and of its rapidly extending field of applications in structural and general engineering work. Gas and electrical welding processes are discussed. Gas cutting is also dealt with and the account includes some statistical data showing the widespread and growing use of welded structures.

The Choice of Gas for Welding Purposes. (Engineering, 1938, vol. 145, Feb. 4, p. 134). The factors affecting the choice of combustible gases for use with oxygen in welding are considered. Whilst acetylene is the most commonly used gas, coal gas, methane, propane, ethylene, benzol and natural gas are also employed. The selection of a gas is often based primarily on its availability and cost and on the cost of equipment for its storage and use, but actually first attention should be given to the question of heat generation, which, if deficient, may give rise to unsound welds. The temperature of all the flames mentioned except the oxy-acetylene flame is below that at which water vapour dissociates, hence some oxidation is bound to occur if gases other than acetylene are used. The use of mixtures of other combustible gases with acetylene is noted. It is concluded that the simple mixture of oxygen and acetylene offers the greatest economic advantage.

The Industrial Application of Acetylene Flames. R. Meslier. (VIII^{e} Séance d'Études Thermiques, Dec. 16, 1937: Chaleur et Industrie, 1938, vol. 19, Jan., pp. 159–162: Revue de la Soudure Autogène, 1938, vol. 30, Jan., pp. 298–301). The author describes different types of oxy-acetylene torch, the production, characteristics and uses of various types of flames resulting from the controlled mixing of the gases and in particular the use of the flame for welding of different types.

Welding Procedure. A Statement of the Problem. E. P. S. Gardner. (Transactions of the Institute of Welding, 1938, vol. 1, Jan., pp. 59–62). The author outlines the problems which require investigation in connection with arc-welding procedure and the main factors involved in such an investigation. Lines along which initial research might proceed are suggested. Reference is made in particular to constructional steelwork.

Metal Deposition in Arc Welding. G. E. Doan. (Welding Journal, 1938, vol. 17, Jan., Supplement, pp. 15–19). The author presents a study of the physics of the formation of the globule of

molten metal on the arc-welding electrode, examines the physical characteristics of the drop in the molten state and the theory of drop detachment and discusses the importance of surface tension in this respect. Experiments are described which indicate that if the surface tension of the molten metal could be lowered and the size of the drop decreased, accelerated welding could be achieved.

American Arc Welding Practice and its Influence on Quality and Cost. J. H. Paterson. (Institute of Welding: Welding Industry, 1938, vol. 6, Feb., pp. 24–36). The author considers the annual consumption of arc-welding material in the United States, and compares it with the consumption of similar materials in England. American practice is discussed with respect to the types of electrodes used, equipment for welding, methods of testing welds and standard specifications for welding technique and materials.

Modern Perfected Resistance Welding and its Importance to the Foundry. F. Schröder. (Giesserei, 1938, vol. 25, Jan. 14, pp. 6–8). After a brief account of the resistance welding process in general the author describes some of the more recent improvements in the method, with particular reference to the so-called "modulation method" and to electron-tube control. The value of resistance welding in the foundry for the production of complicated castings by the welding together of separately cast components, for the welding of alloy steel and iron castings and for repairing broken castings is discussed.

Development of New Resistance Welding Die Materials. F. R. Hensel. (Transactions of the Institute of Welding, 1938, vol. 1, Jan., pp. 25–39). The author discusses the general functions of resistance-welding electrodes and the causes of their deterioration, the physical and chemical requirements of electrodes and new materials meeting such requirements. Testing methods for spot-welding electrodes are next considered and the results of investigations on factors influencing the life of such electrodes are presented. Three appendices deal respectively with a description of a laboratory precision spot welder, pressure and timing synchronism during the welding cycles, and a description of a laboratory gun-welder.

Flash Welding of Rails. (Welding Industry, 1938, vol. 6, Feb., pp. 16–18). A description is given of the mobile plant for flash welding rail joints on the Underground Railway System of the London Passenger Transport Board. The equipment for welding was supplied by the A.I. Electric Welding Appliances, Ltd., and by the A.E.G. In the case of the former machine the complete operation of welding, post-heating and dressing the joint occupies about 10 min.

Butt-Welding of Railroad Rails. R. R. Cummins. (International Acetylene Association, 1937: Welding Journal, 1938, vol. 17, Jan., pp. 46–49). The author describes the butt welding of certain rails on the Central Georgia Railway for the purpose of increasing the service life of rails which have to withstand

severe mechanical conditions and are exposed to strong corrosive influences in a tunnel. The welding was carried out by the oxy-acetylene process; figures are given for gas consumption. The procedure for heat-treating the welded joint is also described.

Repairing the Stem of a Boat with "Trimasic" Steel. (Soudeur-Coupeur, 1938, vol. 17, Jan., pp. 11–12). Reference is made to the use of "Trimasic" steel, a silicon-manganese steel specially developed for torch welding. The mechanical and welding properties of the steel are briefly discussed.

The Construction of Welded Vessels for the Chemical Industry with Reference to the Application of Clad Metals. C. Hase. (Metallwirtschaft, 1938, vol. 17, Feb. 4, pp. 123–131). The author considers the major problems encountered in the choice of material for manufacturing vessels for the chemical industry and then discusses in detail the advantages of clad metals, in particular of corrosion-resisting ferrous and non-ferrous metals or alloys on a steel base. The mechanical properties of clad sheet and the development of methods for the production of heavy sheet are also discussed and the production of internally clad tubes is referred to. The manipulation of clad sheet is dealt with in detail, especially with regard to welding technique, and the essentials of design for various types of equipment are illustrated by a detailed examination of actual plants constructed from steel sheet clad with various metals. A vessel produced from copper-clad steel and in which the contents are heated by eddy currents induced in the cladding by means of a low-tension 50-cycle primary current is described.

Welding of Mechanical and Structural Parts in a General Equipment Shop. A. E. Gibson. (Welding Journal, 1938, vol. 17, Jan., pp. 22–25). The author discusses the economies in cost or weight which may be effected in mechanical and structural components by using standard pressed or rolled sections in place of welded forms of a similar design, and by using welded units in place of castings; more especially the welding of low-alloy steels is discussed and reference is made to the welding of nickel-copper and copper-phosphorus corrosion-resisting steels and of various abrasion-resistant steels.

Development in Welding Large Structures. C. C. Brinton. (Mechanical Engineering, 1938, vol. 60, Jan., pp. 37–41: Welding Journal, 1938, vol. 17, Jan., pp. 33–37.). The author briefly enumerates the economies effected by and mechanical advantages accruing from the replacement of castings by components fabricated from rolled stock by gas cutting and welding. Some factors involved in the transition from casting to welding are dealt with, particularly with respect to available semi-finished products from which components may be fabricated; it is pointed out that welding is only economical when the scrap produced in fabrication is wisely utilised. The welder's work is profitably lightened by providing suitable handling equipment for operations unsuited for

carrying out on automatic machines. Typical components, including cooling and ventilating structures produced by welding are discussed.

Report of Sub-Committee on Welding of Low-Alloy Steels. J. H. Critchett. (Welding Journal, 1938, vol. 17, Jan., Supplement, pp. 8–14). The results of an examination of the literature dealing with the weldability of a number of low-alloy steels for structural and engineering purposes are summarised, together with additional information obtained from a questionnaire. The compositions and conditions of the steels considered are given and the sources of the information are noted. A classification of the steels dealt with into types requiring no special precautions, types requiring care due to a tendency to air-harden and those normally weldable with safety only if subsequently subjected to a stress-relieving treatment, is presented.

Metallurgical Aspects of the Welding of Low Alloy Structural Steels. T. Swinden and L. Reeve. (Transactions of the Institute of Welding, 1938, vol. 1, Jan., pp. 7–24). In the first part of this paper the authors discuss the characteristics of high-tensile steel in relation to design. The value of alloy additions as opposed to increasing carbon contents is stressed and manganese steels, copper-manganese steels and chromium-copper steels are considered. Problems encountered in welding such steels are dealt with and methods are proposed for avoiding them; in particular, the use of titanium to inhibit the formation of a hardened zone behind the weld is discussed. The effects of titanium on the physical properties of an 0·25% carbon steel are examined and the optimum titanium/carbon ratio is shown to be approximately 3. The physical properties of an open-hearth manganese-copper steel are considered in detail. In the second part of the paper the results of welding experiments are presented and discussed; data are given for butt-welded test-pieces in high-tensile steels with and without titanium. Special experiments are described in which the influence of hardenability is investigated, and it is shown that the hardness near a single run of weld metal in the titanium steels is lower than that for steels containing no titanium. The relationship between hardness and the tendency to cracking is then considered and two types of crack are differentiated. The relationship between the type of electrode used and the tendency to cracking is also dealt with. The concluding section deals with certain interesting points of welding technique; the tendency to hardening and cracking near the weld may be controlled by the use of a number of modified techniques which are enumerated and discussed. Finally the effects of stress-relieving treatment and plate thickness are considered.

Shears and Presses Repaired by Bronze Welding. (Soudeur-Coupeur, 1937, vol. 16, Dec., pp. 21–22). Examples are given of the repairing by bronze welding of fractured shears and press frames. Tobin bronze was used as welding rod. Gas-consumption figures are analysed.

Effect of Carbon-Manganese on the Weldability of Plain-Carbon Steels. (Welding Journal, 1938, vol. 17, Jan., Supplement, pp. 2–5). A programme of research to be carried out by the Committee on Plain Carbon Steels of the Industrial Research Division of the Welding Research Committee is outlined. It deals with the effects of carbon and manganese on the weldability of plain-carbon steels and embraces a study of the heat effects on the base metal as revealed by changes in hardness, toughness and tendency to cracking, together with an investigation of the physical properties of the welded joint and parent metal in steels containing varying amounts of carbon and manganese. (*See also* Journ. I. and S.I., 1937, No. II., p. 271 A).

Weld Metal as an Engineering Material and Some Methods of Testing. L. J. Larson. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 22–35). The author discusses the chemical and physical testing and metallurgical examination of weld metal. In addition to standard tests it has been necessary to develop new types of test and to modify standard procedures to obtain the required data on weld metal. The factors governing the quality of weld metal are known, and it is, therefore, possible to control the welding process to produce weld metal which is uniform and reliable.

Distortion of Electrically Welded Mild Steel Structures. R. E. G. Weddell. (Welding Industry, 1938, vol. 6, Feb., pp. 9–12). The author discusses the cause and prevention of distortion in welded mild-steel structures. Electrode size has a pronounced effect in this connection, the minimum distortion being obtained when a small electrode is used with a low current or when a large electrode is used with a heavy current; the reason for this is explained. Distortion is due to expansion and contraction of the weld and base metal and to residual stresses caused by bad design or the use of unsuitable electrode material. Methods of welding which eliminate or reduce distortion are described. The necessity for designing the work for welding and not applying welding technique to a structure intended for riveting is emphasised.

The Relief of Residual Strains and Stresses in Edge-Welded Mild Steel Plates. H. E. L. Martin. (Transactions of the Institute of Welding, 1938, vol. 1, Jan., pp. 44–58). A continuation of a previous investigation. (*See* Journ. I. and S.I., 1936, No. II., p. 215 A). The author investigates the residual strains and stresses in a mild-steel plate hand-welded simultaneously along its two longitudinal edges, the effects of annealing a self-strained mild-steel frame, the initial stresses in which were known to be well within the elastic limit of the material at ordinary temperature, the total residual stresses in an initially annealed mild-steel plate single-edge-welded, and the effects on the residual strains and stresses in double-edge-welded mild-steel plates of applied external tensile loads. The conclusions arrived at as a result of these experiments are discussed in detail.

The Effect of Shrinkage Stresses on the Strength of Welded Structures. E. O. Patton, B. N. Gorbunov and D. I. Berstein. (Ossature Métallique, 1938, vol. 7, Jan., pp. 29–39). A detailed account is presented of the results of an investigation upon the effects of shrinkage stresses on the mechanical properties of welded steel structures. Data are presented in tabular and graphical form.

Concerning the Ban on Welds Working under Conditions of Flexion. H. Gerbeaux. (Revue de la Soudure Autogène, 1938, vol. 30, Jan., pp. 296–297). The author discusses and questions the accuracy of certain conclusions responsible for the prohibition of welded joints in components subjected to bending stresses.

Metal Cutting With the Electric Arc. C. H. Jennings. (Machinist, 1937, vol. 81, Nov. 13, pp. 916–919). The equipment for and technique of cutting ferrous and non-ferrous metals electrically with the aid of graphite or fluxed electrodes are described. Current values and speeds of cutting steel and cast-iron plate and circular bar are presented in graphical and tabular form. Rivet cutting and hole piercing may also be carried out by the arc technique with graphite or coated electrodes.

Deep Cutting in Steel by the Oxygen Jet. (Engineering, 1937, vol. 144, Dec. 17, p. 682). A brief description is given of the procedure adopted for cutting out a core 8 in. in dia. and 25 in. deep from a forged steel billet by means of the oxygen jet. This operation was involved in the manufacture of a gland section for a hydraulic accumulator.

Management of Machine Cutting Operations. R. F. Helmkamp. (International Acetylene Association, 1937 : Welding Journal, 1938, vol. 17, Jan., pp. 25–27). The author discusses the applications, technique and cost of machine-gas-cutting and deals briefly with equipment for cutting metals by this process.

Structural Steels " Flame Softened " during Gas Cutting. H. H. Moss. (International Acetylene Association: Iron Age, 1937, vol. 140, Dec. 30, pp. 22–30; 1938, vol. 141, Jan. 20, pp. 22–27). In the flame-cutting of steel a hardened zone is left on the cut edge. With carbon steels containing 0·3% of carbon and less, the hardness induced is not intense and no difficulty is experienced in bending or fabrication. With high-carbon or alloy steels, however, the hardened surface must be removed either by subsequent annealing or by machining. The author describes the technique and equipment required for flame-softening such hard zones in air- or quench-hardening steels during the cutting process. Discussion is also presented on the macroscopic and microscopic characteristics of untreated and flame-softened surfaces hardened initially during the flame-cutting process. The results of tensile tests on the heat-affected zones of flame-cut and flame-softened hard structural steels are considered and data are presented regarding the comparative costs of various methods of flame-softening. Numerous applications of the process are dealt

with including those for use on air- and quench-hardening structural steels.

Cutting and Tempering of Structural Steels. H. H. Moss. (International Acetylene Association: Welding Journal, 1938, vol. 17, Jan., pp. 7–20). The author discusses the relative effects of the gas-cutting operation on the mechanical properties of carbon and alloy structural steels; in particular the surface hardness acquired by some alloy steels after cutting in this way is noted and the use of the flame-softening technique to overcome difficulties to which this may give rise is dealt with at length; the various types of equipment available for the purpose are described. The results of a detailed investigation of the effects of the cutting and softening treatments upon the microstructure and mechanical properties of various structural alloy steels are presented together with tabular and graphical data.

MACHINING

(Continued from p. 22 A)

Causes and Prevention of Grinding Cracks in Hardened and Ground Tool Steels. J. G. Morrison. (Industrial Heating, 1937, vol. 4, May, pp. 365–368, 378; June, pp. 455–456; Aug., pp. 629–630; Sept., pp. 735–736). A series of articles on the causes and prevention of grinding cracks in hardened tool steels. The effect of poor steel quality, improper heat treatment and improper grinding are dealt with, and information is given on the detection of grinding cracks, the relief of stresses, and the elimination of cracks.

Grinding of Sintered Carbide Tools. M. F. Judkins. (Mechanical Engineering, 1937, vol. 59, Dec., pp. 897–901). The technique and equipment for grinding sintered carbide tools are described; reference is made to the use of diamond wheels and laps. Precautions to be taken in grinding are noted.

How to Polish Stainless Steel Welds. C. H. S. Tupholme. (Sheet Metal Industries, 1938, vol. 12, Jan., pp. 77–78, 80). The author describes the equipment and technique for polishing welds in stainless steel. The limitations imposed by the toughness and hardness of the alloy on the choice of abrasives, grits and disc and wheel forms are discussed together with wheel speeds and methods of avoiding the generation of excessive heat.

Turning Locomotive Tyres. L. Sanderson. (Metallurgia, 1938, vol. 17, Jan., pp. 103–104). The author discusses the tool forms, cutting speeds, cuts and feeds most suitable for turning locomotive tyres which have been worn in service and which may have a hardness equivalent to 120 tons per sq. in. Super-high-speed steel tools are employed (composition of steel not stated). The turning of tyres *in situ* is referred to and some notes are given of the machines and special types of tools used for tyre turning.

CLEANING AND PICKLING OF METALS

(Continued from p. 132 A)

The Use of Compressed Air at a Large Steel Works. (Iron and Steel Industry, 1937, vol. 11, Dec., pp. 103–105). An account is given of the compressed-air plant and of the application of compressed air at the works of Messrs. Steel, Peech and Tozer. The chief application of compressed air at these works is for the operation of chipping hammers to remove surface markings from billets.

Certain Factors Influencing the Pickling Rate of Carbon and Stainless Steels. G. Wallquist, R. Lindberg and F. W. von Walter. (Jernkontorets Annaler, 1937, vol. 121, No. 8, pp. 529–571). (In Swedish.) The authors present a comprehensive discussion of the results of an investigation of the principal factors influencing the pickling rate of low- and high-carbon steels (containing 0·15 and 1·10% of carbon respectively) and of an austenitic nickel-chromium steel containing 0·09% of carbon, 18·5% of chromium and 7·7% of nickel. The apparatus and experimental technique employed are described. The carbon steels were treated with sulphuric acid in concentrations of 5, 10, 20, 40 and 80% by weight at 20°, 40°, 60°, 80° and 95° C. and with hydrochloric acid in concentrations of 5, 10, 20, 30 and 37·32% by weight at the same temperatures. For the stainless steel various mixtures of nitric and hydrochloric acid were used at temperatures of 20°, 40°, 60° and 80° C. The use of inhibitors is referred to. The chemistry of and factors controlling the dissolution of oxides and metal respectively are examined and data are presented in graphical form.

Factors to Watch in the Pickling of Steel. (Sheet Metal Industries, 1938, vol. 12, Jan., p. 31). An English summary is presented of the investigations referred to in the previous abstract.

Handling Waste Acids from Pickling Operations. H. C. Klein. (Wire and Wire Products, 1937, vol. 12, Nov., pp. 701–706). The author discusses the use of ceramic pipes for handling acid effluent from pickling plant and considers the solution of jointing problems by means of the Flexlock joint, which embodies the use of a rubber gasket, the advantages of which are detailed. The use of rubber-lined steel tanks for pickling and the extension of this development to the rubber-lining of welded sheet steel pipes for conveying acid waste are also dealt with. Methods of jointing and erecting such pipe are noted.

COATING OF METALS

(Continued from pp. 133 A–137 A)

Metal Finishing Economics. H. R. Simonds. (Iron Age, 1937 vol. 140, Nov. 25, pp. 32–38). The author discusses the widespread development of nickel electrodeposition, the corrosion resistance of nickel deposits, the physical properties of the deposit, the advantages and disadvantages of nickel as a protective coating, methods of determining the thickness of coatings, bright plating, automatic and barrel plating and economies effected by the use of this process, and the salvaging of worn components by building up an electrodeposited layer of nickel. Prefinished nickel-coated sheet, strip and wire are mentioned together with the applications of such material.

The Selection of Electrodeposits. Properties and Applications of Coatings. C. F. Francis-Carter. (Metal Industry, 1938, vol. 52, Jan. 7, pp. 43–48). The author discusses in detail factors controlling the selection of electrodeposits, their protective value and factors conditioning it, the hardness and wear resistance of deposits, adhesion and the structure of deposits. Deposits of various metals for specific purposes are then considered at length, some indication being given of the characteristics of deposits designed for various purposes.

Electrochemistry of Metallic Coatings. T. P. Hood. (Electrodepositors' Technical Society: Metal Industry, 1937, vol. 51, Dec. 31, pp. 649–652; 1938, vol. 52, Jan. 14, pp. 87–88). The author discusses in detail current knowledge respecting the electrode potentials of metals under the non-equilibrium conditions obtaining in corrosion processes. Particular consideration is given to the behaviour in practice of the so-called " cathodic " and " anodic " metallic coatings. In addition the conditions at pores of metallic coatings are discussed, and a possible electrode-potential test and anodic-oxidation test are outlined.

The Galvanising of Wire. R. Saxton. (Wire Industry, 1937, vol. 4, Dec., pp. 667–671). After a preliminary discussion on the evolution of the hot-dipping process for zinc coating the author discusses briefly the mechanism of the galvanising process and examines in some detail methods of wiping and the use of vulcanised rubber and charcoal wipers. The galvanealing and " Crapo " processes are also dealt with together with the " flame-seal " method. The electrodeposition of zinc by the " Bethanising " method is also considered.

The Electrodeposition of Tin from Acid Sulphate Solutions. A. W. Hothersall and W. N. Bradshaw. (Electrodepositors' Technical Society: Sheet Metal Industries, 1937, vol. 11, Nov., pp. 995–997;

Dec., pp. 1093–1096). (*See* Journ. I. and S.I., 1937, No. II. p. 233 A).

The Hot-Tinning of Fabricated Articles. E. J. Daniels. (Swansea Technical College Metallurgical Society, Jan. 22, 1938). The fabrication of pans, dishes, churns, wire, tubes and other products from copper, steel and other metals produces a surface which requires degreasing, pickling and fluxing before it will take a satisfactory coating of tin by hot dipping. The author discusses variations in procedure and manipulation in these preliminary treatments and in the tinning operation.

Eaglesbush Tinplate Works, Ltd. E. J. Groom. (Sheet Metal Industries, 1937, vol. 11, Nov., pp. 989–990; Dec., pp. 1081–1082). An account is given of the layout of the Eaglesbush Tinplate Works, Neath, Glam., and of the manufacture of tinplate as conducted at these works. The description includes each stage of the process from the delivery of the tinplate bars to assorting and dispatch.

The Welsh Tinplate Industry. I. Williams. (Swansea Technical College Metallurgical Society, Oct. 16, 1937). The author discusses the progress made in the Welsh tinplate industry during the last twenty-five years in connection with technique and equipment. Hot rolling, pickling, annealing, cold-rolling, tinning and cleaning are among the items considered. Future developments are considered under the headings of mechanised mills and strip mills, which, according to the author, constitute alternative lines of progress.

Bronze Spraying a Gate-Type Valve for Water Under Pressure. (Metallwirtschaft, 1938, vol. 17, Feb. 4, pp. 134–135). An extended abstract is given in German of an article by J. C. Gaylord which originally appeared in Power, 1937, vol. 81, No. 9, p. 509. A description is given of the spraying of the inner surface of a gate valve for high-pressure water with bronze. The body of the valve was in cast steel and had previously been copper-plated; heavy wear of the copper had occurred, however. A detailed account of the spraying operation is given, together with data as to gas consumption and the machining of the sprayed coating.

Australian Foundry Practice with Special Reference to Vitreous Enamelling. W. Thomas. (Institute of British Foundrymen and Institute of Vitreous Enamellers: Foundry Trade Journal, 1938, vol. 58, Feb. 3, pp. 121–126). The author outlines the development of the Australian iron and steel industry and gives an account of the Broken Hill Proprietary Company. The position of Australia with regard to raw materials for enamelling, moulding sands and loam is next dealt with, followed by a discussion of the availability of skilled and semi-skilled labour. An account is also given of the position of labour in the vitreous enamelling industry, and of foundry practice and enamelling procedure at a works in Sydney producing a wide range of cast-iron household goods and hardware.

Examination of an Unusual Cast Iron. G. H. Spencer-Strong. (Journal of the American Ceramic Society, 1938, vol. 21, Feb., pp.

60–65). A somewhat detailed study is made of a cast iron which enamelled satisfactorily, but which was characterised by many defects which should have resulted in defective enamelling properties. The chemical analysis showed sulphur 0·11%, an undesirably high value, and manganese 0·36%, a figure which is lower than is usually considered desirable. The casting was examined metallographically; blow-holes were numerous and there were many inclusions of oxides and sulphides. The graphite was both coarse and heavy.

The Analysis of Cast Iron Suitable for Vitreous Enamelling. H. Cowan. (Institute of Vitreous Enamellers: Foundry Trade Journal, 1938, vol. 58, Feb. 3, pp. 126–128, 130). The author discusses the influence of the contents of sulphur, phosphorus, manganese and silicon in cast iron upon the vitreous enamel applied to it; the relative importance of each component is considered, while the problems arising from the effect of annealing upon the form of the carbon in the castings is also dealt with. An ideal analysis is as follows: Total carbon 3·5–3·7%, silicon 2·5–3%, manganese 0·3–0·5%, sulphur 0·06–0·09%, phosphorus 1·4–1·8%. The ideal composition is considered in America to be total carbon 3·4% (of which 0·4% is combined carbon), silicon 2·5%, manganese 0·6%, sulphur 0·08%, phosphorus 0·7%. Foundry difficulties, general and local defects in castings, co-operation between the foundry and the enamelling department and defective enamelling are also discussed.

Study of Metallographic Characteristics and Enamelling Qualities of Certain Cast Irons. R. B. Schaal. (Journal of the American Ceramic Society, 1938, vol. 21, Jan., pp. 24–26). The enamelling properties of three different cast irons are described and their analyses are given. The structure of each iron near the surface before and after enamelling is discussed and the possible influence of structural changes during enamelling upon enamelling qualities is considered. One iron underwent no surface changes during annealing; this sample enamelled better than either of the other two, one of which underwent surface decarburisation and the other of which annealed imperfectly.

Characteristics of Iron and Steel for Porcelain Enamelling. F. R. Porter and J. H. Nead. (Journal of the American Ceramic Society, 1938, vol. 21, Jan. pp. 9–16). The physical and chemical requirements of sheets for porcelain enamelling are discussed, and it is explained why the most satisfactory sheet for the purpose is low in carbon, manganese, sulphur, phosphorus and silicon. Thermal expansion curves are presented for mild steels.

Some Factors Influencing Properties of Acid-Resisting Enamels. G. H. Spencer-Strong. (Journal of the American Ceramic Society, 1938, vol. 21, Jan., pp. 1–8). The effect of metal gauge, firing treatment, drying method, method of application, and base-coat compositions upon the acid resistance and other physical properties was determined upon three acid-resisting enamels of widely varying

types. The firing treatment and method of application, particularly in relationship to the gauge of the metal, were found to affect the acid resistance, while the other factors enumerated affected the physical characteristics to a degree depending on the type of enamel used and the manner in which it was applied. Dust coats were found to be more sensitive to variations in these factors than heavier applications.

Optical Specification of Vitreous Enamels. D. B. Judd, W. N. Harrison and B. J. Sweo. (Journal of the American Ceramic Society, 1938, vol. 21, Jan., pp. 16–23). Data are presented which demonstrate the satisfactory manner in which the reflectance characteristics of vitreous enamels may be specified by the constants, reflectivity and coefficient of scatter. The relationship between reflectance and thickness of material for thin homogeneous layers diffusely illuminated was determined by Kubelka and Munk in whose equation expressing this relationship the hypothetical ideal material is defined by the constants referred to above.

Blistering of Porcelain Enamel on Cast Iron. E. E. Howe and M. E. Manson. (Foundry, 1937, vol. 65, Nov., pp. 35, 95). After a brief preliminary account of problems encountered in determining the cause of blisters in vitreous-enamel coatings on cast iron, the authors describe experiments carried out to elucidate the cause of blistering on a particular cast iron the analysis of which is given. Blistering in this instance appeared to be associated with the production of a surface film of highly stable carbides which, it is suggested, may have arisen owing to the stabilising effect of hydrogen absorbed during casting into green-sand moulds.

The Employment of Thin Asbestos-Cement Coatings in the Battle against Corrosion. (Génie Civil, 1937, vol. 111, Dec. 18, p. 534). An account is given of the composition, properties and methods of application of a patented mixture for use as a protection against corrosion, consisting of asbestos, cement and water. It is said to be suitable for steel and wooden structural work.

PROPERTIES AND TESTS

(Continued from pp. 201 A–215 A)

Inspection, as applied to Iron and Steel. T. Swinden. (Engineering Inspection, 1937–38, vol. 3, Nov.–Jan., pp. 15–24). The author discusses the inspection of iron and steel and comments at length on the significance of physical tests. British Standard Specifications for iron and steel are considered together with the bases upon which specifications are drafted. Specific features of specifications including chemical analysis, problems in connection with non-metallic inclusions and with tests are dealt with, and some reference is made to the need for further research in the fields of physical and mechanical testing. The author next discusses some mechanical tests in common use, including the tensile test, hardness tests, bend test and Izod impact test; special reference is made to the so-called "dimensional effect." Fatigue and damping capacity are commented upon, and the work of French on the relationship between "probable damage lines" and the fatigue-test diagram is noted. Wear tests and tests of mechanical properties at elevated temperatures are also dealt with.

The Tensile Strength of Cast Iron. J. O. Draffin and W. L. Collins. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 88–101). A report is presented on tests made on specimens held in flat and V-notch grips to study the influence of surface defects, on threaded-end specimens, both solid and hollow, to determine the effect of the interior portion on the distribution of stress over the cross-section, and on specimens threaded internally and externally at the ends in order to study the effect of the location of the thread on the strength of the specimen. Strain-gauge readings of longitudinal deformation were taken at small increments of load from zero to the point of fracture on six gauge lines spaced equally around the circumference of the specimen. Tests were made both with axial and with eccentric loading. Abrupt decreases in section appear to weaken the specimen more than surface defects, while little difference was found between the strength of hollow and solid specimens although the latter were slightly stronger. Specimens with inside and outside threads gave practically the same strength.

On the Percentage of Elongation and Contraction of Tensile Test-Pieces. Z. Takenaka. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, Aug., pp. 217–219). (In Japanese). The author proposes to express the percentage elongation of ductile materials in tension by the equations

$$\epsilon = a + bd/l - c(d/l)^n$$

or

$$\epsilon = a + b\sqrt{A}/l - c(\sqrt{A}/l)^n$$

where a, b, c and n are constants, and $\sqrt{A}$ equals the square root of the rectangular cross-section. l is the gauge length and ϵ the elongation per cent. These equations are said to give results in agreement with experimental evidence.

The Influence of the Bending of the Clamps on the Course of the Stress-Strain Curve in Tensile Tests. F. Uebel. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 329–333). Under the assumption that various heavy bending stresses arise during the course of the tensile test, the form of the stress-strain curve is considered from a mathematical standpoint and it is shown that with bending stresses of increasing value the upper yield point in the stress-strain diagram is depressed and may eventually vanish. In addition the limit of proportionality and the elastic limit are affected. The method of determining the value of the superimposed bending stresses is dealt with and it is demonstrated that by making due allowance for such stresses the true value of the upper yield point may be deduced.

The Yield Point in the Tensile Test with Particular Reference to the Influence of the Method of Loading and the Elastic Behaviour of the Testing Machine. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 319–328). Three reports are presented on investigations of yield phenomena during tensile testing with special consideration of the influence of the method of loading and of elastic reaction in the testing machine. In the first report, by E. Siebel and S. Schwaigerer, the authors conclude from their experiments that in order to obtain a stress-strain curve free from disturbances caused by elastic reaction in the testing machine, the tensile test should be carried out to give low speeds of elongation in a machine as rigid as possible. In the second report, by A. Krisch, it is concluded that the upper yield point of mild steel can only be observed with tensile test-pieces subjected to accurate axial stressing. The origin of the upper yield point is discussed and the reasons for its non-appearance with eccentrically loaded specimens are considered. H. Esser discusses in the third report the results of investigations to determine whether the rate of deformation in the region of the yield point is lower with highly rigid machines than with others of less rigid construction, and whether a true lower yield point actually exists.

Stress-Strain Diagram of Mild Steel in Relation to the Elastic Reaction of the Testing Machine. G. Welter and S. Gockowski. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., Nos. 3–4, pp. 118–125). (In Polish). The authors present a description of investigations on the stress-strain diagram of mild steel in relation to the method of loading and to the elastic reactions exhibited by the testing machine. A description is given of the apparatus and technique employed and phenomena observed are critically discussed. Results are presented in tabular and graphical form.

On a Stress-Strain Diagram of Repeated Load Tests. S. Higuchi. (Technology Reports of the Tôhoku Imperial University, 1937, vol. 12, No. 3, pp. 59–68). From a stress-strain diagram obtained by repeated-load tests, the following conclusions were drawn : The mechanical properties of a material, such as the yield point, breaking stress, &c., cannot be directly determined for repeated-load tests from a load-deformation diagram or from data usually derived from a torsion diagram as in the case of static tests. To determine the stress at any point in a test-piece for repeated loading, three factors are required : The load or the outer moment and its acceleration; the frequency of the load or of the outer moment; and the resonance-frequency characteristics of the test-piece.

Yield Points of Mild-Steel Bars Under a Force of Bending and Torsion Combined. F. Nakanishi. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, Nov., pp. 290-292). (In Japanese). If to a mild-steel bar subjected to a bending moment B a torsional moment T is applied, then, if T is gradually increased, yield eventually occurs along an inclined section. The author has calculated the relationship between B and T. If the stress at a point in a specimen of mild steel reaches the limiting shear stress, local yielding occurs. This takes place when T is relatively small and B relatively large. The calculated results agree well with those obtained by experiment.

A Fundamental Study of the Design of Impact Test Specimens. H. C. Mann. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 102–111). The author discusses fundamental data regarding the effect of notch form, velocity of impact and the temperature of the specimen on the energy values obtained from the tension-impact test. Low-temperature embrittlement is shown to be due to impact velocity and notch form. The shortcomings of the flexural-type specimen are considered and the necessity for taking into account the velocity effect when information is required on the true dynamic properties of the material is emphasised.

Contribution to the Standardisation of the Impact Test-Pieces. V. Jareš. (Čechoslovakische Normungsgesellschaft und der Čechoslovakische Verband für Materialprüfung, Prague, 1937). The author discusses the results of a series of tests devoted to the clarification of certain problems arising as a result of efforts to standardise internationally the form of impact test-pieces. The analyses, mechanical properties in general and the microstructures of his specimens are presented. The relative merits of different notch forms are examined. Graphical and tabular data are presented.

Stress Distribution in Springs. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Jan. 29, pp. 124–125). An abstract (with additional data on helical springs) is presented of a paper on stress distribution in springs by E. Lehr and A. Weigand

which appeared originally in Forschung auf dem Gebiete des Ingenieurwesens, 1937, vol. 8, p. 161. Methods of calculating the stresses in springs of various types are discussed.

The Degree of Fatigue of Carbon Steels under Reversed Bendings. F. Ôshiba. (Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Dec., pp. 323–339). Specimens of Swedish carbon steel were tested in reversed bending on Ono's fatigue testing machine, the progress of fatigue being followed by the method of Honda. With specimens of uniform diameter the progress of fatigue under a stress of constant intensity increases at a diminishing rate as the number of stress repetitions increases. Its final value at the instant of fracture becomes less as the intensity of stress decreases. Even under a low stress, such as one below the limit of endurance, a degree of fatigue is found and becomes almost constant in a later range of stress repetitions. The true limit of endurance may, therefore, be determined by means of an applied stress below which the degree of fatigue remains constant for a definite number of repeated loadings. In the case of notched specimens the degree of fatigue progresses first slowly, then rapidly and finally again slowly as the number of repetitions increases; this is analogous to the course of fatigue progression under repeated impact.

Concerning Endurance Tests on Flange Reinforcements on Tension Bars and Girders. O. Graf. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Feb. 12, pp. 158–160). The author discusses the results of endurance tests on girders and tension members. Previous investigations had indicated that properly executed butt welds on structural components of this type were better suited to withstanding repeated loads than fillet welds. In addition improvements were also made in fillet welds, which could not be entirely dispensed with. The best forms for both types of joint are suggested on the basis of the series of repeated tensile or bend tests made in the author's investigation.

Research on Fatigue Properties of Heavy Helical Springs. C. T. Edgerton. (American Society of Mechanical Engineers, Sub-Committee on Heavy Helical Springs of the Special Research Committee, Progress Report No. 3: Wire and Wire Products, 1938, vol. 13, Jan., pp. 17–26, 41; Feb., pp. 69–73, 97). A comprehensive survey is presented of an investigation into the fatigue properties of helical springs. The following spring materials have been tested or are to be tested in the course of the research: Carbon basic open-hearth steel; electric carbon steel; electrically melted silicon-vanadium steel. Of these materials, initial results and an analysis of data so far obtained are presented for the first two only. The composition of the electric carbon steel was as follows: Carbon 1·05%, manganese 0·21%, phosphorus 0·008%, sulphur 0·011%, silicon 0·27%, chromium 0·04% and nickel 0·09%. The manufacture of this material into springs, details of heat treatment and the mechanical properties of the finished articles are discussed. Tabular

data are presented regarding the endurance tests and the results obtained are critically reviewed.

Damping Capacity and Ageing of Steel. S. L. Case. (Metal Progress, 1938, vol. 33, Jan., pp. 54–60). An extension of a previous discussion devoted to a consideration of the " work sensitivity test " for embrittlement through cold-work. (*See* p. 139 A). It is pointed out that the test previously mentioned is subject to the limitations of the Izod test; damping capacity is little affected by heat treatment and is not appreciably influenced by localised segregation or by mechanical defects, and is capable, therefore, of providing corroborative evidence in support of the previous test. The evaluation of damping capacity and a simplified testing equipment are discussed together with some consideration on the possible relationship between this property and grain size and certain other physical properties; as a result of numerous experiments the author found no well marked correlation between these properties. Typical damping capacity data are presented for seven carbon steels. It is concluded that the damping capacity of steel is strongly influenced by cold-work. A summarised analysis of conclusions arrived at as a result of a number of tests on different steels is given, and data are presented in tabular and graphical form.

Hardness Testing. J. Woolman. (Sheffield Society of Production Engineers, Nov. 1, 1937 : Iron and Steel Industry, 1938, vol. 11, Jan., pp. 131–136; Feb., pp. 179–181). The author describes various types of machines for hardness testing which employ a diamond or spherical steel indenting tool, and considers the methods of using the machines and their limitations. Included among the types described are the Avery and Rockwell testing machines and the Brinell, Johnson, Herbert, and Vickers hardness-testing machines. The Shore Monotron and Herbert pendulum tester are also referred to. Among the impact hardness testing machines noted are the Shore scleroscope and the Auto puncher. Tests by mutual indentation are also noted.

Concerning the Influence of the Manner of Deformation on Ageing and Recrystallisation. W. Lamarche. (Dissertation, Technische Hochschule, Braunschweig, 1937 : Mitteilungen der Kohle- und Eisenforschung G.m.b.H., 1937, vol. 1, Oct., No. 9, pp. 181–198). The influence of the manner of deformation upon ageing and recrystallisation phenomena was investigated upon Armco iron (0·02% of carbon) subjected to cold-working by processes of extension, compression and drawing to varying degrees. Recrystallisation phenomena were examined by means of grain-size determinations before and after different annealing treatments. Ageing was investigated by the determination of alterations in the impact strength. No difference could be detected in the effects of either of the three deformation processes upon ageing, but the degree of deformation exerted a marked influence; as the degree of deformation increased the impact strength decreased. The effect of previous mechanical

treatment upon recrystallised specimens could not be detected by means of impact tests. Deformation by compression occasioned, in the critical recrystallisation area, a grain size after recrystallisation about three times as great as that caused by mechanical elongation or drawing. Tests with specimens subjected to bending confirmed these results. No influence of grain size on impact strength was observed, but, on the other hand, crystal grains of equal size but produced by normalisation and by a heat treatment causing recrystallisation respectively exhibited a different influence on the course of the impact-strength temperature curve. The recrystallised specimens gave lower impact values for given grain sizes than the normalised specimens.

Some Special Wear-Resisting Materials for Clay Machinery Parts. J. O. Everhart. (Journal of the American Ceramic Society, 1938, vol. 21, Feb., pp. 69–72). The results of experiments carried out on about fifty alloy cast irons and steels to determine their wear resistance when used in the form of components for clay-working machinery are described. Tests were carried out over a period of 2·5 years and the parts tested comprised pug-mill knives, repress die liners, muller tyres, dry-pan runner plates and dry-pan screen plates. Data are presented in tabular form. It is concluded that the Brinell hardness of the materials gives little guide to their wearing properties.

On the Volatilisation of Manganese from Manganese-Bearing Iron Alloys. W. Baukloh and H. Uehlinger. (Metallwirtschaft, 1938, vol. 17, Jan. 28, pp. 85–87). By heating iron-manganese and iron-manganese-carbon alloys *in vacuo* and in a stream of hydrogen it was shown that appreciable vaporisation of the manganese occurred *in vacuo* at 800° C.; in hydrogen such vaporisation was diminished. Carbon decreased the vaporisation at 800° C., but had little effect at higher temperatures.

New Equipment for Creep Tests at Elevated Temperatures. P. G. McVetty. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 235–257). A creep testing machine is described which enables twelve to sixty tests at different stresses to be made in the same furnace. The furnace consists of a large cylindrical mass of alloy steel containing twelve vertical holes at intervals of 30° for the specimens being stressed and a larger central hole for the pretreatment of specimens without stress. Test specimens are supported on knife edges and are loaded by twelve radial levers and weights which hang in an annular space in the base of the apparatus. The wall of the furnace consists of polished concentric shells of nickel and aluminium separated by powdered Sil-o-cel powder and rotates on ball bearings to facilitate creep measurement. Two methods of creep measurement are possible with this equipment, one involving the use of comparison rods, the other a specially designed travelling micrometer microscope. The furnace is provided with automatic voltage and temperature control and

controls may be added to compensate for variations in the room temperature.

Selection of Steels for High Temperatures. M. Fleishmann. (Steel, 1938, vol. 102, Jan. 17, pp. 34–39). The author considers the mechanical properties of steels at high temperatures and the effect upon these properties of the corrosion- and scale-resistance of the material. In particular creep strength is discussed. A new testing procedure is outlined which it is anticipated may throw further light upon the strength of materials at high temperatures. Specimens are stressed at various loads until fracture occurs; the loads causing rupture are then plotted on logarithmic co-ordinates against the time which elapses before the specimen breaks. Curves obtained in this way are apparently straight lines and extrapolation is possible to time periods equivalent to the commercial life desired. Curves obtained for Timken 4–6 chromium-molybdenum steel and for "Sicromo 5" are discussed; breaks in the curve for the first material are apparently due to oxidation increasing with prolonged heating. The simplicity of the test is emphasised. The influence of various additions of chromium, molybdenum, silicon, aluminium, titanium and niobium on the corrosion- or scale-resisting properties of steels is discussed and the effect of varying the carbon contents is considered. The influence of the microstructure and of mechanical working is dealt with. Particular reference is made to engineering problems in the oil industry, certain proprietary brands of steel are mentioned, and data are presented in graphical form.

Hydrogen Attack of Steel. (Metallurgia, 1938, vol. 11, Feb., pp. 108–110). A summary in English is presented of a paper by F. K. Naumann on the effect of hydrogen under high pressure on carbon steel which appeared originally in Stahl und Eisen, 1937, vol. 57, Aug. 12, pp. 889–898. (*See* Journ. I. and S.I., 1937, No. II., p. 244 A).

Preparation of Pure Metals. A. E. van Arkel. (Réunion Internationale de Physique, Chimie et Biologie, Paris, Oct., 1937 : Métaux et Corrosion, 1937, vol. 12, Dec., pp. 219–223). To evaluate the quality of a pure metal, chemical analytical methods are, in general, of little value since they do not as a rule give an indication of the oxygen content. In some cases the thermal dissociation method yields metals free from oxygen; iron is included among the metals mentioned by the author. In comparing the properties of metals prepared by this method with those of metals prepared by other methods it is demonstrated that sometimes the physical and mechanical properties are profoundly influenced by traces of oxygen; this occurs when solid solutions of the metals and their oxides are present. When such solid solutions are not formed the effect of oxygen on the mechanical properties is relatively insignificant. Thorium containing up to 20% of thoria retains its electrical and mechanical properties almost unaffected. (*See* following abstract).

Conclusions from the Discussion on Professor van Arkel's Paper. G. Chaudron. (Métaux et Corrosion, 1937, vol. 12, Dec., pp. 223–226). The author summarises the salient features of the discussion upon van Arkel's paper on the preparation of pure metals (*see* preceding abstract). Reference is made to the preparation of oxygen-free iron and it is pointed out that deoxidising agents do not, in general, decrease the oxygen content of this metal but merely distribute it in a different manner. The Perrin process, in which the iron melt is emulsified with slag and then decanted and which is said to effect a more complete purification than other methods, is noted. Reference is also made to the work of Yensen and of Esser on the transformation phenomena in very pure iron.

The Metallurgy of Cast Iron. A. E. Peace and P. A. Russell. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Feb. 10, pp. 135–137; Feb. 17, pp. 165–166). The authors consider the relationship between the hardness of cast iron and its microstructure, the effect of various elements on the forms assumed by the carbon in the cast iron, the effects of elements forming solid solutions and intermetallic compounds, the effects of varying the cooling rate of the molten iron and of heat treatment, and the influence of graphite, phosphorus, sulphur and manganese on the mechanical strength, pressure tightness and freedom from porosity and resistance to heat.

Late Silicon Additions to Cast Iron. V. A. Crosby and A. J. Herzig. (Foundry, 1938, vol. 66, Jan., pp. 28–29, 73). The authors discuss the results of a series of experiments to determine the relationship between the physical properties obtained in a cast iron and the time and quantity of silicon additions made subsequently to the melting of the charge. Experimental heats were melted in silica crucibles in a 30-lb. induction furnace. The normal analysis of the irons produced was total carbon 3·0%, silicon 2·0% and manganese 0·90%; varying proportions of the silicon content were added as late additions. The experimental technique is described in detail. The structural and mechanical properties of the irons obtained are examined. With an iron of the composition referred to, silicon may be added as a late addition with advantage in amounts up to 75% of the total silicon content, but late additions in excess of this result in wild heats. Late silicon additions made as described tend to eliminate dendritic formations. The tensile strength of cast irons of the analysis stated may be increased by as much as 12,000 lb. per sq. in. by the late addition of part of the silicon.

Composition and Microstructure of Ancient Iron Castings. M. L. Pinel, T. T. Read and T. A. Wright. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 882: Metals Technology, 1938, vol. 5, Jan., No. 1). The authors present a comprehensive account of the chemical compositions and microstructures of eleven specimens of early Chinese iron castings,

the dates of which are accurately known and which cover the period from 502 to 1093 A.D.

Developments in the Production of Malleable Castings.—XI. Properties. H. H. Shepherd. (Iron and Steel Industry, 1938, vol. 11, Jan., pp. 122–126). The author discusses the mechanical and physical properties of malleable castings. It is noted that the repeated impact test offers a very critical means of judging the resistance of malleable cast iron to shock fatigue, and the Stanton test is considered at some length. Machinability and corrosion resistance are examined. In discussing the properties of whiteheart malleable cast iron it is stated that the resistance of this type to abrasional or frictional wear is superior to that of blackheart malleable cast iron. The special properties of whiteheart malleable cast iron for the electrical industries are also dealt with. In conclusion certain aspects of importance in connection with the testing procedure for malleable cast irons are discussed. (*See* p. 148 A).

The Hot and Cold Working of Malleable Cast Iron. J. V. Murray. (Metallurgia, 1938, vol. 17, Jan., pp. 85–87). The results of experiments show that the strength and hardness of malleable cast iron are increased by hot-working. In addition homogeneity is promoted, and nodular carbon is elongated; primary graphite, however, will not elongate on rolling. Overheated malleable cast iron is unsuitable for rolling except with special precautions, as free cementite is present; this material must be treated like steel and not subjected initially to too heavy a reduction. Cold-working is possible and, by suitable intermediate annealing treatment, may be carried out to any desired extent; such cold-working enhances the tensile strength and Brinell hardness, but reduces the ductility. The experiments were carried out on whiteheart malleable cast iron. High-silicon malleable cast iron is not amenable to the treatments discussed.

Economies by the Use of Interchangeable Wearing Parts. A. Kreuels. (Stahl und Eisen, 1938, vol. 58, Feb. 3, pp. 109–112). Efforts to economise in structural materials and to reduce their consumption to a minimum as well as to reduce maintenance costs are illustrated by numerous examples drawn from rolling-mill equipment. Better lubrication, the choice of suitable materials and modifications in the design of parts subjected to wear are discussed.

The Relation Between the Mechanical Properties of Ferrous Materials and the Liability to Breakdown in Service. L. W. Schuster. (Midland Metallurgical Societies: Metallurgia, 1938, vol. 17, Jan., pp. 81–82). The author discusses the lack of correlation between the results of the more usual mechanical tests and breakdown phenomena exhibited by materials in service. Such tests cannot be employed to indicate fully the behaviour of a material in actual service.

Account of Research in Connection with the Progressive Development of Metallic Materials. F. Körber. (Jernkontorets Annaler,

1937, vol. 121, No. 11, pp. 676–690). (In Swedish). The author gives an account of the evolution and present status of the chemical, physical, mechanical and metallographical testing of metals and indicates the state of present knowledge in connection with these properties of metallic substances and its technical importance.

Influence of Non-Metallic Inclusions on the Mechanical Properties of Chromium-Molybdenum Structural Steels. II. S. Pilarski and S. Jaźwiński. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., No. 3–4, pp. 139–144). (In Polish). A continuation of previous work. (*See* Journ. I. and S.I., 1937, No. II., p. 281A). The authors deal with the mechanical properties of two chromium-molybdenum structural steels *A* and *B*, the first without inclusions and the second with inclusions. Test-pieces were cut parallel to and at right angles to the direction of the fibre structure. It appears that, independently of the heat treatment to which the steel has been subjected, the tensile strength, yield point, elongation, reduction of area and impact strengths of steel *B* are lower than those of steel *A*, the greatest difference being shown in the case of specimens taken parallel to the direction of the fibre structure and heat-treated at 620° C. Fatigue tests carried out on an Amsler rotating-beam testing machine on specimens taken at right angles to the direction of fibre structure gave greater values for *A* than for *B*, both being in the heat-treated state. The fatigue limit under repeated impact-bending stresses for heat-treated specimens taken in a direction parallel to the fibre structure is greater for steel *B* than for steel *A*.

Contribution to the Knowledge of the Austenitic Chromium-Manganese Steels. H. Legat. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 337–341). Investigation of the microstructure and magnetic properties was employed to determine the limits of the stability of austenite in the diagram of the iron-chromium-manganese-carbon system with carbon between 0·1 and 0·2%. The mechanical properties and workability of steels with manganese 12–43%, chromium 0–18%, carbon 0·10–1·0% and additions of silicon 0·03–1·0%, nickel 0–4·0%, copper 0–6·0% and molybdenum 0–6·0%, were determined in the forged, annealed and quenched conditions. In the stable-austenite region the lowest tensile strengths at about 5% of chromium rise with increasing manganese contents; the yield point reaches a maximum at about 7% of chromium and 33% of manganese. Regarding the machinability, steels with carbon up to 0·3% may be economically worked with cutting tools, but the machinability decreases rapidly with higher carbon contents.

Chromium-Manganese Steels as Heat-Resisting Steels. J. H. G. Monypenny. (Metallurgia, 1938, vol. 17, Jan., pp. 93–96). A continuation of a previous article (*see* p. 148 A). The author discusses in greater detail chromium-manganese steels within those ranges of composition which appear to possess the necessary thermal structural stability. Steels within this range are considered in regard to

their physical and mechanical properties and resistance to scaling; the effects of heat treatment are dealt with and some attention is devoted to the structural characteristics of the materials. The maximum chromium content must be restricted to prevent the formation of any appreciable amounts of FeCr, and those steels suitable for practical use exhibit adequate resistance to scaling in air up to a temperature of 800° C.; this value may be extended to possibly 900° C. by the use of rather less satisfactory alloys containing 18–20% of chromium and 8–9% of manganese. These steels resist sulphurous gases better than nickel-chromium steels. The advantages of additions of silicon are discussed and it is noted that silicon-bearing chromium-manganese steels which resist scaling up to 1100° C. are said to have been produced.

Progress in Stainless and Heat-Resisting Steels. L. Sanderson. (Engineering and Boiler House Review, 1938, vol. 51, Jan., pp. 458–460). Among the steels referred to by the author are the following: An austenitic steel containing high silicon and tungsten and with a tensile strength of 9 tons per sq. in. at 870° C.; this steel forms a very adherent scale which does not readily flake at 1095° C. and hence contributes to the heat and corrosion resistance of the material; the 12% manganese, 9% chromium stainless steel developed in Russia and Germany, which, whilst possessing a pleasing white colour and high resistance to corrosion, is said, however, to be inferior in some respects to the normal type of stainless steel containing 18% of chromium and 8% of nickel; a steel containing 0·3% of carbon, 0·8% of manganese, 1·5% of nickel and 0·12% of vanadium, which is said to be a more satisfactory material for furnace-charging boxes than cast carbon steel in so far as it is mechanically stronger and gives increased service life; "Nemicle" molybdenum-bearing acid-resisting alloy developed by Endo, which is claimed to be resistant to 20% hydrochloric acid and little affected by the 30% acid; an "intermediate" stainless steel containing 0·15% of carbon, 8–10% of chromium, 0·5% of manganese, 0·5% of silicon, and 1·25–1·75% of molybdenum, which is said to possess excellent corrosion-resisting properties in damp unfavourable atmospheres and to be reasonably resistant to heat; a copper-bearing stainless steel containing 18% of chromium, 8% of manganese, 1·0% of copper and 0·1% of carbon, which is said to possess excellent mechanical properties and to be readily machined or rolled or drawn and to be cheaper and more easily welded than the 18/8 type. A range of heat-resisting steels containing molybdenum, a nickel-chromium-manganese steel for pressure vessels, and a 1·5–2·75% chromium steel containing vanadium and molybdenum are also noted. Among heat-resisting steels the 39% nickel 10% chromium steels are briefly discussed and reference is made to a steel suitable in the cast form for power-plant fittings operating at high temperatures; its composition is nickel 2·05%, chromium 0·8%, carbon 0·35%. The so-called "Armstrong" metal, containing 0·1% of carbon, 4–6% of

manganese, 17·5% of chromium, 2·9% of copper and 8·0% of nickel is also mentioned; it is readily machined, has good corrosion-resisting properties, particularly to sulphuric acid, and does not work-harden. It is designed to replace 18/8 where heat treatment of the cold-worked or welded component is not practicable; it is not intended as a complete substitute for 18/8, however.

The Factor of Safety of Reinforced Concrete Beams Stressed in Bending, when using Torstahl Grade 45/10 and also the Comparative Determination of the Safety Factor when using St 37.11 and High-Duty Steels with Yield Points of 3600 kg. per sq. cm. and over. T. Titze. (Zeitschrift des Österreichischen Ingenieur und Architekten Vereines, 1938, vol. 90, Feb. 18, pp. 47–50). An examination from the mathematical standpoint of factors of safety of reinforced concrete beams is presented and the advantages to be gained by using steels of high yield point are demonstrated. A brand of steel known as " Torstahl Grade 45/10 " is referred to, the use of which ensures the safety factor being never less than 2.

Quality and Economy of Beams Produced from Steel Scrap. H. Bronneck. (Österreichische Bauzeitung: Montanistische Rundschau, 1938, vol. 30, Feb. 16, Stahlbau-Technik, pp. 4–6). The author discusses the use of old rails as a substitute for relatively expensive new steel girders in light building construction. The precautions to be observed in dealing with a material which has probably been in heavy service for a number of years are outlined; work-hardening, brittleness due to ageing and hair cracks are referred to and methods of detecting such defects are noted. Experience gained in Germany in the use of such material is examined at length. Some indications are given of the methods for testing such scrap and it is remarked that the maximum bending loads to which old rails and girders should be subjected must not in general exceed about 6 tons per sq. in. The mechanical properties of new girders and beams worked up from scrap are compared, data being presented in tabular form.

The Reconstruction of Chelsea Bridge. E. J. Buckton and H. J. Freeday. (Journal of the Institution of Civil Engineers, 1938, Jan., No. 3, pp. 383–429). In Appendix II. of the authors' paper details are presented of the composition and mechanical properties of certain high-tensile steels used in the structural work of Chelsea Bridge. " Ducol," manufactured by Colvilles, Ltd., and containing approximately 0·26% of carbon, 0·13% of silicon, 0·36% of copper and 1·52% of manganese, and " Atlantes " steel, manufactured by the Cargo Fleet Iron Co., Ltd., and containing approximately 0·25% of carbon, 0·12% of silicon, 0·43% of copper, 0·92% of manganese and 0·44% of chromium, are examined; the first gives a yield point of 24·84 tons per sq. in., and an ultimate strength of 41·46 tons per sq. in. and elongation of 21·5–20·98%, whilst the second gives a yield point of 25·02 tons per sq. in., an ultimate strength of 39·21 tons per sq. in. and elongation of 21·07–21·04%. Some discussion

is also presented on the selection and testing of materials from which to manufacture rivets for jointing girders made of the steels already described. The material selected possessed a tensile strength of 30–34·5 tons per sq. in. in the form of bars and of 37·1–46·6 tons per sq. in. in the form of driven rivets together with a shear strength of 26·2–31·3 tons per sq. in. and 26–19% elongation on 2 in.

Fundamental Considerations Regarding the Introduction of Steel as a Constructional Material for Machine Tools. C. Krug. (Stahl und Eisen, 1938, vol. 58, Jan. 13, pp. 34–36). The author examines from a mathematical standpoint the reactions of rigid and non-rigid structures to dynamic stresses and applies the conceptions established to a criticism of machine design and of the basis governing the choice of structural materials employed. In particular the choice of cast iron on account of its higher damping capacity as compared with steel (both materials having been tested in the form of test-pieces) is strongly criticised.

Nickel and its Alloys at the International Exhibition at Paris, 1937. J. Lasnaret. (Revue de Métallurgie, Mémoires, 1937, vol. 34, pp. 630–643). Reference is made to the mechanical, physical and magnetic properties of nickel-bearing ferrous alloys and to machines and equipment for demonstrating and determining such properties.

Nickel Alloys in Japanese Machine Tools. T. Matsuda. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 12–20). In discussing the production in Japan of heavy and precision machine tools, the author outlines briefly the structural details of such machines in which, for strength and rigidity, nickel-bearing cast iron and alloy steels containing nickel are used extensively.

Some Special Cases of Defects Encountered in Marine Engines and Boilers. S. F. Dorey. (Afdeeling Werktuig-en Scheepsbouw of the Kon. Institut van Ingenieurs, Dec. 10, 1937). The author describes the results of investigations of breakdowns in marine engines and boilers; cases are considered under the headings of defects in boilers, welded joints, machinery forgings, piston rods, bolts, and screwshafts. The results of mechanical and metallographical tests are discussed and the causes of failure are demonstrated or deduced.

Application of Nickel Alloy Steels and Cast Irons in the Tool and Die Field. J. W. Sands. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 21–24). The author discusses the use of nickel-bearing case-hardening steels, medium- and high-carbon oil-hardening steels containing nickel and nickel-bearing cast irons in tool and die production. The properties and special applications of each type of material are considered, and tabular data are presented in which such applications of steels or irons of specific compositions (S.A.E. specifications) are referred to for which details of appropriate heat treatments are given. Reference is made to the production of dies for pressing or stamping by pressing a specimen between blocks of nickel-chromium cast iron.

Nickel-Containing Hard Alloys for Tools. T. Kase. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 25–52). The author discusses the compositions, mechanical and physical properties, heat treatment and applications to tool production of hard nickel-bearing alloys. Nickel and nickel-chromium steels, case-hardening nickel-molybdenum steels, hard nickel cast iron and nickel-chromium cast irons, tool steels containing nickel in conjunction with cobalt, tungsten or molybdenum and other alloy additions, stellite and related alloys, hard-carbide-base hard metals containing nickel, the tungsten-molybdenum-chromium and tantalum-molybdenum-iron alloys (Sendalloy) and the nickel-boron alloys, and nickel-bearing high-speed steels are dealt with. Tabular and graphical data are presented giving analyses and mechanical and other properties.

Materials for Precision Machinery. C. Fujii. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 53–76). The author discusses the requirements of materials for the construction of precision machinery such as mechanical testing equipment and high-grade machine tools. Suitable materials are considered under different heads including those adapted for the construction of beds and frameworks, spindles, gears and nut and screws. Nickel and nickel-chromium steels (including the high-alloy types) and cast irons find extensive application. Tabular data are presented.

Use of Nickel in Precision High-Speed Machine Tools. W. R. Gorham. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 77–82). An account is given of the use of nickel alloys in high-speed precision tools manufactured by the National Precision Machine Co., Ltd. (Japan). A feature of these machines is the high spindle speed at which they operate. The extensive use of a pearlitic nickel-chromium cast iron with a tensile strength of about 36 tons per sq. in. is referred to, also the use of a 3% nickel, 1·0% chromium case-hardening steel (produced in the electric furnace) for gears. The compositions of other steels are also noted.

Nickel Alloys in Machine Tools. H. Okuda. (Japan Nickel Review, 1938, vol. 6, Jan., pp. 83–93). The author presents a comprehensive review of nickel alloy steels and cast irons, the composition, mechanical and physical properties of which are discussed, which fulfil the high duties required of structural materials employed in the construction of modern high-production machine tools. The use of non-ferrous alloys containing nickel is also dealt with.

Materials Recommended for Machine and Hand Tools in England. (Mond Nickel Co., Ltd., Bureau of Information on Nickel, Publication AA5: Japan Nickel Review, 1938, vol. 6, Jan., pp. 94–105). Tabular data are presented regarding the materials, and their appropriate heat treatments, for the construction of components for machine and hand tools of a wide range of types; nickel-bearing alloy steels and cast irons together with various non-ferrous alloys containing nickel are included in the tables, of which two are devoted to a presentation of the analyses of steels and cast irons.

High-Speed Steels Low in Tungsten. (Metallurgist, 1938, vol. 11, Feb., pp. 101–102). An English summary is presented of the work of R. Scherer and of E. Houdremont and H. Schrader upon low-tungsten and tungsten-free high-speed steels which appeared originally in Stahl und Eisen, 1937, vol. 57, Nov. 25, pp. 1317–1322; Dec. 2, pp. 1355–1359. (*See* pp. 151 A, 152 A).

Mechanical Properties of Rolled Sections as a Function of the Location of the Test-Piece. G. Welter and M. S. Wolagiewicz. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., No. 3–4, pp. 126–138). (In Polish). The authors note that the mechanical properties of components made of structural steels will vary according to the part of the ingot from which they are rolled; similarly, it is pointed out, the mechanical properties cannot be judged equally from test-pieces cut from the flanges or web of a girder or in a direction parallel to or at right angles to the direction of rolling, in which process weakening of the material may be caused which will strongly influence the quality of the component. Investigations on rolled girders were undertaken to clarify the problems to which these considerations give rise; determinations were made of the tensile strength, elongation, reduction of area, impact strength, hardness, chemical composition, microstructure, macrostructure, non-metallic inclusions and the influence of the position of the slots or grooves in the rolled section. The results of the investigations show that at every stage in the processing of the ingot to form the finished girder unavoidable circumstances arise which may adversely affect the chemical composition, structure and mechanical properties of the component, particularly the impact strength. Due consideration must be given to these facts when interpreting the results of test-pieces cut from the component under examination.

Improving the Free-Cutting Steels. J. D. Armour. (Metal Progress, 1938, vol. 33, Jan., pp. 60–64). The author refers to the testing of the " production value " of free-cutting steels on a specially adapted four-spindle automatic screw machine and then discusses in detail different types of free-cutting steel and notes particularly the need for a theoretical knowledge of the properties responsible for free-machining qualities. Carbon improves the machinability up to about 0·3%; manganese and phosphorus also confer free-cutting properties, the former in amounts up to 1·5% with carbon less than 0·2%, the latter within the limits found in commercial steel or up to about 0·15%. Silicon has not been found to improve the machining properties of the high-sulphur free-cutting steels. The relation between the sulphur content and machinability is said to be a straight-line function; the sulphur content of a steel is determined by quality requirements on the one hand and by rolling-mill difficulties on the other. The optimum compositions of different types of free-cutting steels are discussed at length, together with the important part played by cold-working in improving machinability.

Recent Progress in Nickel Steel Castings. (Foundry Trade

Journal, 1938, vol. 58, Jan. 6, pp. 3–5). The influence of nickel upon the mechanical properties of steel castings is discussed at length, and the resultant effect of the improvements obtained upon design is noted. Uniformity of structure in both thin and thick sections, increased resistance to shock and abrasion, and suitability for use at high temperatures are referred to among the advantages conferred by nickel additions. The heat treatment of nickel steel castings is also dealt with. Typical compositions are tabulated.

Bearing Metals and Materials. H. N. Bassett. (Metal Industry, 1938, vol. 52, Jan. 7, pp. 25–32). Reference is made under the heading of sintered metal bearings to the production in Russia of porous bearings from a mixture of pure iron powder and graphite which is pressed, and sintered in an inert medium at 900–1000° C. Bearings with 3·5% of graphite are reported to possess a porosity of 30–40%, a Brinell hardness of 25–30, and to have anti-friction properties superior to those of either white metal or bronze.

The New Laboratories of Crane, Limited. V. C. Faulkner. (Foundry Trade Journal, 1938, vol. 58, Feb. 10, pp. 142–144). An account is given of the research laboratories of Crane, Ltd., Nacton Works, Ipswich. The laboratory equipment is described in some detail. A large malleable cast iron foundry is attached to the works and it is noted that the laboratory equipment for both routine and research testing in this connection consists largely of apparatus standardised by the American Foundrymen's Association.

The Laboratory for the Testing of Metals at the Pavilion of Applied Mechanical Technique in France. L. Guillet, J. Galibourg and A. Sourdillon. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Nov., pp. 621–629). An account is given of equipment for the preparation of test-pieces, for conducting mechanical tests and for the determination of strain by photo-elastic methods exhibited at the International Exhibition, Paris, 1937.

British Standard Specification for General Grey Iron Castings, Grades A and C. (British Standards Institution, No. 321–1938). This is the first revision of this specification since it was prepared in 1928. The principal alterations consist of the addition of a small test bar 0·6 in. in dia., and of an intermediate size between the 1·2-in. and 2·2 (now 2·1)-in. dia. test bars, namely, 1·6-in. in dia. Corresponding changes are made in the cast sections to which these sizes of test bar apply.

British Standard Specification for High Duty Iron Castings, Grades 1, 2 and 3. (British Standards Institution, No. 786–1938). In view of the demand for improved grades of cast iron having a tensile breaking strength greater than 12 tons per sq. in., this specification was authorised by the Iron and Steel Industry Committee and was prepared by the Technical Committee which prepared B.S. No. 321 for General Grey Iron Castings (Grades A and C). High-duty cast iron is usually more expensive to produce than ordinary cast iron, particularly in the higher grades. Moreover the production of cast-

ings in high-duty cast iron often involves special technique. The specification therefore covers the process of manufacture, chemical composition, moulding, freedom from defects, provision of test bars and their dimensions, mechanical tests, transverse tests, tensile tests, inspection and testing facilities. In the Appendices will be found a summary of testing requirements, transverse rupture stress (modulus of rupture) and factors K for converting actual breaking loads into transverse rupture stresses, and other important information.

British Standard Specification for Wrought Iron Tubes and Tubulars, Gas (Light), Water (Medium) and Steam (Heavy) Qualities. (British Standards Institution, No. 788–1938). This specification applies to welded, screwed and socketed wrought-iron tubes and tubulars and plain-end wrought-iron tubes of nominal bores from $\frac{1}{8}$ in. to 6 in. inclusive.

British Standard Specification for Steel Tubes and Tubulars, Gas (Light), Water (Medium) and Steam (Heavy) Qualities. (British Standards Institution, No. 789–1938). This specification applies to welded and weldless, screwed and socketed steel tubes and tubulars and plain-end steel tubes of nominal bores from $\frac{1}{8}$ in. to 6 in. inclusive. It does not apply to plain-end pipes for water and gas which fall within the scope of B.S. S.534, "Steel Spigot and Socket Pipes for Water, Gas and Sewage." The requirements of the present specifications are applicable to tubes which would come within the scope of screwed and socketed.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 216 A–219 A)

Steel Structures Identified and Flaws Located by Means of Balancing Wave Tests. C. Kinsley. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 36–49). Non-destructive tests are carried out to determine the degree or lack of uniformity of samples of steel by means of electromagnetic measurements with a dynamometer and subsidiary phase-shifting coil. The method of conducting the test, which consists first in balancing out an induced electromotive force in the testing circuit by an equal but opposing electromotive force synthesised from the phase-shifting transformer, the steel being in the untreated state, and afterwards evaluating the amplitude and phase angle of the induced electromotive force in the sample after it has been treated to change its structure, is described in detail. Typical structural differences produced by variation in section or heat treatment are discussed and the location of a crack in a rod is described.

Results, New Possibilities and Limitations of X-Ray and Gamma-Ray Irradiation. R. Berthold. (Stahl und Eisen, 1938, vol. 58, Jan. 20, pp. 49–52). Whilst porosity, segregation and the presence of inclusions are readily detected by the X-ray or gamma-ray techniques, the detection of fine cracks is considerably more difficult. Radiography has found its widest application in the examination of welds, but it is difficult to decide the degree of harm which may be expected from flaws detected in this way. Further developments in the use of this method may be expected as progress is made in equipment design; special attention is directed to the hollow-anode tube and to the electron-count tube of Geiger and Müller with which section thicknesses may be determined in industrial practice.

Alterations in the Crystal Condition of Metals under Reversed Stressing as shown by the Radiograph. F. Wever, M. Hempel and H. Möller. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 315–318). The authors describe X-ray investigations carried out on a 0·02% carbon steel in order to clarify somewhat contradictory statements regarding the behaviour of a crystal lattice subjected to reversed stressing. It is concluded that for loads well below the maximum strength under reversed stressing no visible alteration of the radiograph occurs, but with loads above this value very obvious lattice variations can be observed. With loads a little below the maximum strength under reversed stressing unmistakable alterations can be detected in the crystal structure. Finally, regarding the behaviour of a material under alternating stress, it is of little moment whether lattice distortion is initially present or not.

A Study of Oxide Films Formed on Heated Iron. T. Iimori. (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1937, vol. 34, Dec., pp. 60–67). The oxide film formed on iron at various temperatures and pressures of air was studied by means of electron diffraction. A diagram showing the favourable conditions for the formation of the various oxides was obtained. Regarding the stability of superficial lower oxides, migration of iron atoms into the oxide layer is suggested. Only γ ferric oxide was formed below 340° C. on the surface of etched iron, whereas on the polished surface α ferric oxide formed under the same conditions. An unknown new primary oxide was found to be formed at lower temperatures.

Notes on the Graphitisation of Gray Cast Iron. R. M. Parke, V. A. Crosby and A. J. Herzig. (Metals and Alloys, 1938, vol. 9, Jan., pp. 9–14). The mechanism of the formation of graphite in grey iron is discussed and an explanation is proposed for the occurrence of primary ferrite between areas of carbide and pearlite.

The Estimation of Inter-Granular Surfaces and Volumes in Metals. H. F. Kaiser. (Metals and Alloys, 1938, vol. 9, Jan., pp. 23–26). The author discusses briefly the principal types of geometrical solid from which aggregates may be constructed and then passes on to a consideration of a quantitative method for the derivation of grain boundary data with respect to metals; the problem is treated from the mathematical standpoint. The application of the equations derived to the estimation of the relative amount of insoluble impurity at the grain boundaries is discussed at length.

The Effect of the Cooling Rate upon the Quantity of Pro-eutectoid Ferrite. J. A. Verö. (Royal Hungarian Palatine-Joseph University of Technical and Economic Sciences, Publications of the Department of Mining and Metallurgy, 1937, vol. 9, pp. 192–209). From a series of experiments involving the cooling at different rates of specimens of carbon steel containing from 0·06 to 0·71% of carbon the author concludes that the slow cooling usual in practice does not produce conditions of equilibrium; that the straight-line relationship between the amount of ferrite observed and the carbon content of the specimen only holds for equilibrium conditions, and that in other cases the relationship is represented by curves departing progressively from a straight line with increasing cooling rates; that steels consisting of nearly equal proportions of ferrite and pearlite are most affected by variations of cooling rate, while those consisting mainly of either ferrite or pearlite are influenced to a smaller degree; and that a simple relationship exists between the quantity of the constituents present and the type of structure produced. The technique and apparatus employed are described in detail.

CORROSION OF IRON AND STEEL

(Continued from pp. 220 A–223 A)

Anode and Cathode Weight Losses in Galvanic Corrosion. W. A. Wesley. (Electrochemical Society, Apr., 1938, Preprint No. 5). Simple relationships between the current flow and the corrosion rates of iron anodes and cathodes have been suggested previously but do not appear to be accepted as fundamentally sound. Experiments carried out with a number of metals and alloys have demonstrated that the relationships mentioned are more applicable than has been hitherto believed; it was found that the anode weight loss in galvanic corrosion tests was approximately equal to the sum of the loss due to normal corrosion together with that calculated from the galvanic current by Faraday's law; for corrosion of the oxygen-depolarisation type the decrease in the corrosion of the cathode was roughly equivalent to the current; the " protective current density " was that equivalent to the normal rate of cathode corrosion in the same corrosive medium.

Differential Aeration Currents in Corrosion. U. R. Evans and T. P. Hoar. (Journal of the Society of Chemical Industry, 1938, vol. 57, Jan., p. 23T). The authors discuss the principle of differential aeration with the acceptance of which Bengough and Wormwell disagree. It is shown, nevertheless, that by means of this principle many phenomena observed in engineering practice may be interpreted. Reference is made to investigations carried out by the Soil Corrosion Staff of the United States Bureau of Standards and to other work.

Corrosion of Iron-Chromium-Aluminium Alloys. (Metallurgist, 1938, vol. 11, Feb., pp. 110–111). An English summary is presented of an article by W. Baumann which appeared originally in Metallwirtschaft, 1937, vol. 16, Dec. 3, pp. 1267–1269. (*See* p. 220 A).

Corrosion Resistance of Aluminium Alloys with and without Protective Coatings, of a Magnesium Alloy and of Mild Steel in a 3% Salt Spray. G. Welter and W. Maruszewska. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., pp. 93–99). (In Polish). The results of corrosion tests on a number of light alloys and on a mild steel containing 0·16% of carbon, 0·44% of manganese, 0·23% of silicon, 0·012% of phosphorus, 0·010% of sulphur and 0·13% of copper are described, the tests being carried out in a spray of 3% aqueous sodium chloride. It is noted that the corrosion resistance of the steel is superior to that of aluminium alloys of the duralumin type.

Effect of Sulphuric Acid on Metals and Alloys. R. Müller. (Korrosion und Metallschutz, 1938, vol. 14, Jan., pp. 28–34). The author discusses the resistance to corrosion by sulphuric acid of a

number of metals and alloys, including iron, 18/14 chromium-nickel steel, 28/14 nickel-silicon-copper steel and Niresist. It is pointed out that the corrosive effects of the acid, like those of other corrosive media, are conditioned by a number of factors such as the concentration of dissolved oxygen, hydrogen-ion concentration, temperature, the velocity of relative movement between the acid and metal and the formation of films of the products of corrosion on the surface of the metal; each of these factors is discussed in detail, together with quantitative and qualitative methods for the determination of corrosion. The results of laboratory experiments are examined and corrosion phenomena of different types dealt with in some detail. The alteration of the physical properties of metals by corrosion are then discussed and finally special corrosion problems in certain industries are briefly referred to.

Fissuring of Carbon Steel under the Influence of Corrosion and Mechanical Stresses. M. Śmialowski. (Wiadomości Instytutu Metalurgii i Metaloznawstwa, 1937, vol. 4, Sept.–Dec., No. 3–4, pp. 100–105). (In Polish). Examples of corrosion cracking in steel, particularly under the influence of nitrate solutions, cited in the literature are discussed. Observations on corrosion in girders are also reported with particular reference to girders in an ammonium nitrate works in which serious cracking had occurred. Results of experiments on the influence of static stresses in the presence of boiling 50% aqueous ammonium nitrate upon annealed steel wires 1–2 mm. in dia. are described and graphical data are presented regarding the influence of this treatment on mild steel containing 0·08% of carbon, 0·29% of manganese and 0·12% of copper and an electrolytic iron containing 0·005% of carbon and 0·08% of manganese. Failure of the wires occurred at stresses equal to 26–33% of the normal tensile strength in a few hours. The apparatus employed in the investigation and the technique of conducting the experiments are described in detail.

The Attack of Superheated Steam on Steels. (Metallurgist, 1938, vol. 11, Feb., pp. 99–101). A review is presented of the work of Potter, Salberg and Hawkins and of Jenkins, Tapsell, Mellor and Johnson on the oxidation of steels by superheated steam. The steels so far investigated by the first authors comprise a mild steel, a carbon-molybdenum steel, a silicon-molybdenum steel and three chromium-molybdenum steels. It is noted that whilst no tests have yet been carried out on chromium-nickel steels of the 18/8 type, considerable insight into their behaviour has been gained from a study of the austenitic steels employed in the construction of the high-pressure boiler. It is shown that at temperatures of 540° C. and over austenitic steels used for superheaters are attacked with the production of hydrogen and a black layer of oxide which decreases the rate of reaction as the duration of exposure increases. Important conclusions are drawn from this observation as to the behaviour of steels for superheater tubes in practice. Attempts to measure

the progress of attack upon mild steel by determining the hydrogen produced failed; the reasons for this are discussed. Subsequently results were based on the weight of oxide removed from the interior of the specimens at the conclusion of each test. Tabular data are presented from which it may be seen that the oxidation rates of all the alloy steels tested were about two-thirds of those for mild steels. The authors conclude that pressure is without serious effect on oxidation in steam. The investigations at the National Physical Laboratory yielded results for low-carbon steels which agreed substantially with those of Potter, Salberg and Hawkins.

Pitting of Steel Under Lubricated Rolling Contact and Allowable Pressure on Tooth Profiles. T. Nishihara and T. Kobayashi. (Transactions of the Society of Mechanical Engineers, Japan, 1937, vol. 3, Nov., pp. 292–298). (In Japanese). The author describes the results of experiments on the pitting of lubricated mild-steel cylinders subjected to rolling contact with 22% slip. The loss by abrasion was measured by weighing every 22 hr.; a sudden increase in this loss indicated the onset of pitting. Provided that the contact pressure does not exceed a certain limit, depending on the material being tested, pitting will not occur within a finite number of repetitions of stress; the limiting values found for the mild-steel specimens are compared with the endurance limits under repeated compressive stress. Values for other materials are also reported. At a sufficiently high ratio of slip the tendency to pitting is practically inhibited.

Résumé of Symposium on Correlation Between Accelerated Laboratory Tests and Service Tests on Protective and Decorative Coatings. A. C. Elm. (Proceedings of the American Society for Testing Materials, 1937, vol. 37, Part 2, pp. 467–477). An abstract is presented of papers read at a symposium on the correlation between accelerated laboratory tests and service tests on protective and decorative coatings which formed part of the 1937 Annual Meeting of the American Society for Testing Materials. Among the topics discussed are tests in connection with finishes for indoor service, paints for iron and steel and paints for exterior use on wood.

BOOK NOTICES

(Continued from pp. 227 A–230 A)

AUWERS, O. VON : "*Magnetische und elektrische Eigenschaften des Eisens und seiner Legierungen. Aus Gmelins Handbuch der anorganischen Chemie.*" Herausgegeben von der Deutschen Chemischen Gesellschaft. 8vo. Illustrated. Berlin, 1938 : Verlag Chemie, G.m.b.H. (Price 84 RM.)

This volume contains the combined contributions of Dr. Auwers on the magnetic and electrical properties of iron and its alloys to Gmelins Handbuch der anorganischen Chemie. The work appeared originally in System Number 59 (Iron) of the Handbuch as Section 7 of Part A, a portion of Part D, and of the supplementary volume Part D 1. These parts have been reproduced here without modification, the pages retaining the same numbers as they did in the Handbuch, but the index is very complete, and no difficulty should be encountered in finding any required section. The printing is very clear, and the diagrams, six hundred and twenty-eight in all, are distinct in spite of the thin paper necessitated by the number of pages in the volume. It is quite impossible for a reviewer to deal adequately with a work of this kind. It suffices to say that it represents ten years' patient work on the part of its author, himself a distinguished contributor to modern knowledge on the subject. All the literature up to September, 1937, has been reviewed, abstracted, and classified. The work involved must have been immense, and the book will be indispensable to those requiring a critical survey of existing knowledge of the magnetic and electrical properties of ferrous materials. The work is not a textbook, but is intended for those familiar with the fundamentals of the subjects dealt with, and it should enable any aspect of these to be surveyed up to the most modern contributions. As an example of thorough careful work, Dr. Auwers' book must rank very high, and scientific workers in many subjects will be indebted to the author for his methodical and critical treatment of a vast mass of material.

STEPHEN L. ROBERTON.

RUMMEL, K. "*Der Einfluss des Mischvorgangs auf der Verbrennung von Gas und Luft in Feuerungen.*" pp. 84. Illustrated. Düsseldorf, 1937 : Verlag Stahleisen m.b.H. (Price 6.75 RM.)

Professor Dr.-Ing. Kurt Rummel, Manager of the Energie- und Betriebswirtschaftstelle (Wärmestelle) des Vereins deutscher Eisenhüttenleute, has collected into book form a series of articles on the influence of the mixing process on the combustion of gas and air in furnaces which appeared originally in Archiv für das Eisenhüttenwesen. Abstracts of these articles will be found in the Journal of the Iron and Steel Institute, 1937, No. II., pp. 124 A, 166 A, 253 A, and in Section II. of this Journal, p. 54 A. In his introduction the author explains that the researches he discusses are of a preliminary character only, and that they are confined to a study of the mixing of gas and air streams which emerge from suitable orifices and come into contact in a space in which they are free to intermingle. The account is divided into four main sections, dealing respectively

with theoretical considerations, investigations of the influence of port or burner design, investigations of the mixing of gas and air streams by means of specially modelled equipment, and the verification of the results obtained with the experimental apparatus mentioned under the previous head. Each of the four sections is again subdivided and each is provided with a summary. The author expresses the hope that this report will arouse the interest of other workers to extend further the investigations he describes, and that it will assist in establishing the technique of furnace designing on other than empirical grounds.

TROUBINE, K. G. "*Gases in Steel.*" pp. 123. Moscow and Leningrad, 1937: Glavnaya Redaktsiya Literaturi po Chernoy Metallurgii. (Price 2R. 75K.)

Information on gases in steel scattered throughout the literature has been systematised with a view to arriving at some general conclusions. The results of different researches, however, are often very conflicting, owing to imperfections in methods of investigation of this kind on solid steel on the one hand, and to discrepancies in the results obtained by different experimental methods on the other. Studies of gases evolved from the liquid metal during its solidification are more reliable and more valuable for the investigation of phenomena concerning the solubility of gases in steel. Gases evolved from liquid steel during its solidification consist essentially of carbon monoxide and hydrogen, and change their relative composition according to the following law: The carbon-monoxide content rises to a certain maximum, and then drops at a constant rate to a value approaching zero; the hydrogen content varies in the opposite direction. The evolution of carbon dioxide and methane is insignificant, and the nitrogen content remains at a practically constant level during the whole process of solidification (1·5–3%). In converter steels the volume of gases evolved is about twenty times the volume of the ingot. The amount of gas given off diminishes as the steel cools in the ingot mould, and at the moment of complete solidification most of it is eliminated. Rimming steel evolves more gas than killed steel. The author explains the absence of visible boiling in killed steel by this fact as well as by its increased viscosity in comparison with rimming steel.

Regarding the relative composition of the gas evolved from killed steel, the carbon monoxide content is lower and the hydrogen content higher than in rimming steel. The amount of gas depends largely on the quality of the raw materials employed. An increase of manganese in rimming steel raises the hydrogen content and diminishes the nitrogen content. In Bessemer steel the nitrogen content is diminished by deoxidising with aluminium or zirconium.

Comparing the results of investigations on various metallurgical processes, no definite relationship can be established between the composition and the amount of gas in steel and the process by which it was made. Only with respect to contamination by nitrogen do steels produced in the converter and the electric-arc furnace differ sharply from other steels. Acid and basic open-hearth steels are equivalent to those produced in the crucible and the high-frequency furnace in this regard. Steel melted by the Talbot open-hearth process is purer with respect to nitrogen, owing, probably, to the protective action of the covering slag.

During the melting of steel the nitrogen content of the bath always rises, regardless of the process employed, and this increase continues during pouring. Alloying elements exert a considerable effect on the solubility of gases. In most alloy steels the gas content is higher

than in carbon steel. During hot extraction *in vacuo* the maximum evolution of gas occurs near the critical points of the steel. The author discusses the origin of gases in steels produced by different metallurgical processes and the nature of their solutions. The work of the Committee on the Heterogeneity of Steel Ingots of the Iron and Steel Institute is among that referred to and considered in detail.

Discussing phenomena associated with the solution of gases in steel, the author concludes that the formation of the pipe in killed steel and of blow-holes in rimming steel is the result of the evolution of gases during freezing, since the contraction of steel in the solid as well as in the liquid state is caused primarily by the evolution of gases. The various forms of the voids in killed and rimming steels are associated with the different viscosities of these steels in the liquid state, as well as with the different amounts of gases. These conclusions are based upon a comparison of the diagrams showing the changes in the specific gravity of steel and in the solubility of hydrogen in iron with temperature drawn by Sieverts. The maximum evolution of gases near the point of solidification and other phenomena observed in steel foundry practice are also brought forward in support of these conclusions.

The author supplements his earlier views on shrinkage as the cause of blow-holes in rimming steel, and demonstrates that shrinkage itself is a result of the evolution of gases from solidifying steel. The author associates the formation of surface blisters in steel ingots with the splashing of steel when top-poured, during which process air is mechanically entrapped by the globules of metal owing to the high surface tension of liquid steel; later the gases are evolved and accumulate in the splashes in the form of "shrinkage cavities." When the metal in the ingot mould rises to the level of the zone of splashing, the bubbles of gas and air penetrate into the body of the liquid, forming elongated blisters the axes of which take the direction of the resultant of two components: The force of attraction to the ingot axis (*i.e.*, in the direction of minimum viscosity) and the tendency to travel upwards (*i.e.*, due to their specific gravity).

The author considers certain well-recognised defects in steel from the standpoint of gas solubility (flakes, hair-cracks, &c.), discusses the effect of gases on the mechanical and magnetic properties of steel and advances some conjectures as to the possible relationship between the volume and heat-conductivity changes of steel in the solid state and the gases dissolved in it. He notes that the variations in the coefficient of thermal expansion of steel have apparently not been studied *in vacuo* or in gases other than air.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Werkstoff-Handbuch, Stahl und Eisen.*" Herausgegeben vom Verein deutscher Eisenhüttenleute. 2., vollständig neu bearbeitete Auflage. 8vo. Illustrated. Düsseldorf, 1937: Verlag Stahleisen m.b.H. (Price 25.90 RM.)

The first edition of this well-known book appeared in 1927 as a loose-leaf book of reference on iron and steel. The intention behind the choice of binding was to keep the handbook up to date by revision, replacement and addition when occasion arose. During the last ten years this intention was carried out by the issue of new sections and corrections for existing sections, but now the old edition has outgrown the original covers, and a completely new binding accompanies the present edition. It may be said that there does not appear to be much room in the new covers for the accommodation of further leaflets, and as the whole book is now approaching the limit of convenient size,

the next change in format might well be a filing box for loose sheets with a smaller loose-leaf cover for those sections of immediate importance. The handbook follows the same lines as the earlier edition, each section of several pages, written by an expert, being quite independent of the rest of the book, and containing its own references to important literature on the subject dealt with. The sections are arranged under an alphabetic system of classification, but there is also a comprehensive index, and no difficulty is experienced in finding the information available on any subject even if two or three sections have each something to contribute on the matter. There are five main sections into which the pages are grouped, and this enables many items to be found without reference to the index at all. The first group contains information of a general nature, such as the atomic constants, weights of steel sections, and the properties of pure iron, along with a section on the size variation resulting from different methods of metal forming. The next group of contributions deals with the properties of steel and the methods of testing these. The physical properties are dealt with very adequately in separate sections, and in addition to a full treatment of the usual mechanical properties, wearing, welding and machining properties are also given full consideration. The properties and treatment of the multitude of steels in current use are covered in the next two sections from different standpoints. First the steels are classified according to composition, and all the ternary and some quaternary steels are considered separately. Included in this part of the handbook are contributions on steel castings, cast iron, and malleable iron. In the following part steels are classified according to their uses, separate treatment being accorded to case-hardening steels, valve steels, file steels, and so on, thirty-seven different applications of steel being considered in all. These two parts of the handbook enable the properties, treatment and general characteristics of practically any steel to be found if its composition is known, and also the types of steel, with their properties and treatment, used for any specific application. The last part of the book reverts to the general, and covers the treatment and testing of steel, typical headings being the iron-carbon diagram, case-hardening, pickling, non-destructive testing, and statistical methods of evaluating results. There are in all one hundred and four separate sections, of which fourteen appear in this edition for the first time, and thirty-nine of the remainder have been completely rewritten. The usefulness of the handbook is beyond question, and all the information is concise and accurate, standard works having been freely drawn on for material and data. As a reference book for steel metallurgists this handbook is quite unequalled, and it is an outstanding example of the modern practice of team work in the production of technical literature.

STEPHEN L. ROBERTON.

"*Zeitschrift für angewandte Mineralogie.*" Herausgegeben von F. K. Drescher-Kaden. Band 1, Heft I. 8vo. pp. iv + 96. Illustrated. Berlin, 1937: Verlag von Gebrüder Borntraeger.

This new addition to German periodicals is edited by Professor Dr. Fr. Drescher-Kaden of the Mineralogical Institute of the University of Göttingen, with the assistance of a company of distinguished associates. Further issues will appear at intervals, and about four numbers will constitute a volume. In his foreword the editor states that the title "Applied Mineralogy" will be interpreted liberally, and the contents of the first issue are in accordance with his statement. The articles in this number are, "The strength and work-hardening of rock salt,"

by W. Schmidt; "The heavy mineral sands of the Baltic littoral and their distribution under wave action," by W. von Engelhardt: "The quantitative spectroscopic determination of gold in alluvial gravels," by G. Claus, Fr. Hegemann and Fr. Rost; "A contribution to the crystal chemistry of alloys. Section I. Examination of the ternary section $MgZn_2$–$MgAg_2$," by H. Witte; and "The spectrographic determination of molybdenum and vanadium in the Richelsdorf slag heaps," by E. Preuss. Future issues will include a section of abstracts of recent work on applied mineralogy that has been published in other periodicals.

STEPHEN L. ROBERTON.

MINERAL RESOURCES

(Continued from pp. 168 A–169 A)

Economic Geology of the Central Coalfield. Area I.—Kilsyth and Kirkintilloch. T. Robertson and D. Haldane. (Memoirs of the Geological Survey of Scotland, Edinburgh, 1937). The geology of the Kilsyth and Kirkintilloch area of the central coalfield of Scotland is described from the economic standpoint. It is noted that no ironstone has been worked in the area under discussion since about 1920, but a list of the deposits which have been worked is given.

The Geology of Parts of the Minbu, Myingyan, Pakokku and Lower Chindwin Districts. G. de P. Cotter. (Memoirs of the Geological Survey of India, 1938, vol. 72, Part I., pp. 126–133). Under the heading of economic geology the author discusses the occurrence of petroleum in the area of Burma reported upon and points out that it is unlikely that any new oilfields of commercial value will be found. The geology of local coal deposits is also considered, some analyses being given. The coals are in general of low quality and of little economic value.

Petroleum in New Zealand. J. Henderson. (New Zealand Journal of Science and Technology, 1937, vol. 19, Dec., pp. 401–426). The author considers the possible domestic petroleum resources of New Zealand. Likely districts are dealt with from a geological standpoint and some reference is made to geophysical prospecting.

Some Researches on the Mineralogical Composition of Our Iron-Bearing Minerals. R. Stumper. (Revue Technique Luxembourgeoise, 1937, vol. 29, Nov.–Dec., pp. 286–293). After a preliminary discussion on the geology and mineralogy of the minette ores of the Lorraine-Luxemburg area, and some reference to the difficulties involved in analysing complex minerals of this type, the author indicates the amounts of the minor metallic constituents present in the ores, and deals, *inter alia*, with the results of a thermal analysis (by the differential method) of iron-bearing and other minerals.

Concerning Mining in Greece. K. Schlittermann. (Berg- und Huttenmännische Monatshefte, 1938, vol. 86, Jan.–Feb., pp. 16–20). The mineral resources of Greece are very extensive but capital for their development is lacking, and modern equipment is employed to a very limited extent. Sources of magnesite, pyrites, chrome and nickel ores, manganese ores and coal are discussed and some indications given of the methods employed for their exploitation. The occurrence of molybdenum glance containing up to 3% of molybdenum near the Bulgarian border is noted.

The Eska Creek Coal Deposits, Matanuska Valley, Alaska. R. Tuck. (United States Geological Survey, 1937, Bulletin 880–D). The author discusses the geology of the Eska Creek coal deposits, Alaska. They form part of the Matanuska coalfield and constitute one of the two commercial coal-producing districts in the country. It is stated that there are reserves of several millions of tons of recoverable coal in the area.

Iron-Ore Resources of Paraná, Brazil. V. Leinz. (Zeitschrift für praktische Geologie, 1938, vol. 46, Jan., pp. 1–5). The geology and mineralogy of the iron ore deposits of Paraná (Brazil) are discussed. Reference is made to the low titanium content of magnetites found in this district, to the deposits of itabirite and to the deposits of manganiferous rock, which, in the unweathered state, analyses about 19·7% of manganese, but in the weathered condition exhibits an oxidised layer assaying about 33% of manganese; the commercial value of both types as sources of manganese is discussed.

FUEL

(Continued from pp. 236 A–239 A)

Improved Method for the Determination of the Calorific Value of Liquid Fuels in Platinum Calorimeters. M. Richter and M. Jaeschke. (Angewandte Chemie, 1938, vol. 51, Mar. 12, pp. 146–147). The authors describe an improved method of determining the calorific value of a liquid fuel in the Berthelot-Mahler-Kroeker bomb calorimeter; the gelatine capsule commonly used is replaced by a collodion capsule the advantages of which lie in its easy combustibility, non-hygroscopic qualities and its low weight. The results of tests are presented in tabular form.

Velocity of Propagation of Flame in a Combustible Homogeneous Mixture under Constant Pressure. Theory of the Blue Cone. Ribaud. (VIII[e] Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 23–27). A mathematical study of the propagation of combustion in a homogeneous mixture of gases under constant pressure.

Theory of the Velocity of Propagation of Flames (Deflagration). Ribaud. (VIII[e] Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 28–32). The author presents a study of the physics of flame propagation.

The Velocity of Propagation of Combustion. Uniform Movement of the Flame. P. Laffitte. (VIII[e] Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 33–37). The author discusses a new characteristic of combustible gaseous mixtures, namely, the fundamental velocity of the flame. The velocity of uniform movement of a flame in complex mixtures of gases may be calculated by the law of Payman and Wheeler.

Researches Concerning the Identification of Chemical Reactions Occurring in the Interior of Flames. Prettre. (VIII[e] Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 38–43). It is not yet possible to determine the nature and velocity of the chemical reactions occurring in a flame which result in the transformation of the reactants taking part in the combustion into compounds thermodynamically stable with respect to temperatures attained outside the zone of combustion. Nevertheless it has been definitely established that highly reactive and thermodynamically unstable compounds are formed at an intermediate stage in this transformation. Studies of the kinetics of the reactions and of the chemical properties of the intermediate products of combustion indicate that more exact and complete knowledge on flame reactions will soon be attained.

Experimental Determination of Flame Temperatures. Methods and Results. Y. Laure and H. Gaudry. (VIII[e] Séance d'Études

Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 44–53). The authors discuss thermo-electric methods of different types for measuring the temperature of flames, optical methods, a chemical method and a method based upon the determination of the electrical conductivity of the flame. The results of experimental determinations of the flame temperatures of different gases are briefly presented.

Calculation of Flame Temperatures by the Method of Successive Approximations. P. Montagne. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 54–62). The author presents a mathematical exposition of the method of calculating flame temperatures by the process of successive approximations. The fundamental hypothesis upon which this method is based is that the products of combustion of a gaseous mixture are in a state of equilibrium at the maximum temperature developed by the process of combustion. If losses by radiation during the course of the reactions involved in combustion are neglected, then the heat produced by such reactions is all employed in raising the temperature of the burnt gases.

Surface Combustion by Projection. H. Cassan. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 125–135). The author discusses the theory and practice of surface combustion and describes equipment for utilising the phenomenon. Salt baths, a heat-treatment furnace for tools and a continuous furnace for the treatment of wire—all operating on this principle—are referred to.

The Utilisation of Pre-mixed Gas Flames in Laboratory and Industrial Furnaces. G. Meker. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 178–182). The author describes the thermal characteristics and utilisation of flames produced by mixtures deficient in air, and by homogeneous mixtures. The influence of the surface upon which the flame impinges on its combustion characteristics is dealt with, and the utilisation of waste heat in the combustion gases for preheating purposes is also touched on; two-stage muffle or hearth furnaces are referred to. The use of air preheated by recuperation and of flames produced by liquid fuels are also dealt with.

Limitations to the Use of Pre-mixed Gas Flames in Siderurgical Furnaces. C. Le Chatelier. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 183–184). The author discusses the advantages and limitations of pre-mixed gas flames for use with furnaces designed for various siderurgical purposes. Certain modern furnace designs are briefly considered.

Surface Combustion Processes Resulting from the Infusion of a Combustible Gaseous Mixture through a Refractory Mass. A. Gouffé. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et

Industrie, 1938, vol. 19, Jan., pp. 185–190). The author discusses the theory and practice of surface combustion by infusion, notes the advantages of such a process and concludes that when heat transmission by radiation is deemed preferable to any other method, then surface combustion by infusion offers the best and most economic means of attaining this end.

Some Considerations on the Applications of Pre-mixed Gas Flames in Furnaces, and on Surface Combustion. E. Damour. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 191–194). The author describes the applications of pre-mixed gas flames and concludes that the short hot flames which may be obtained by this system can be advantageously employed in industry as the method permits of a degree of control generally impossible with systems characterised by progressive combustion. The need for a systematised terminology in describing flames is stressed.

Experiences with Industrial Flames. H. Guillon. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 195–196). The author describes the measurement of the temperature of a blast-furnace-gas flame employed to heat a water-tube boiler, and of the temperature of the flame in a coal-fired boiler fitted with a chain-grate stoker.

Conditions of Temperature and Heat Transfer in the Laboratory of the Industrial Furnace. Part I. Heat Flow and its Temperature Range. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 363–374). The author describes the thermal processes occurring in the laboratory of a furnace, draws up a heat balance for a section of this space and expresses the individual items of the heat balance in the form of a systematic series of equations. Consideration of the heat flow in the laboratory provides an explanation of the properties and the significance of the temperature field, and indicates the character of the heating process as a disturbance in the equilibrium of a field of some given final temperature to which the working space tends to attain. The author next considers the calculation of the heat exchange by convection and radiation between flue gases, the charge and the furnace walls. Finally the absorption properties of the flue gases are discussed and the special treatment necessary when dealing quantitatively with their radiating properties is examined. (*See* following abstract).

Conditions of Temperature and Heat Transfer in the Laboratory of the Industrial Furnace. Part II., Calculation of Wall Temperature and the Total Heat Transfer. H. Schwiedessen. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Mar., pp. 431–442). The author continues his discussion on the conditions of temperature and heat transfer in the laboratory of industrial furnaces. (*See* previous abstract). The chief factors governing the wall temperature and the total heat transfer are the mean tem-

perature across a section of the laboratory, the heat-absorbing capacity of the combustion gases, the surface condition of the laboratory, heat losses by way of the walls, and the temperature difference between the furnace walls and the charge. Each of these factors is discussed in detail together with the effects of radiation from walls and combustion gases, and convection, which in furnaces used in iron smelting, with a mean temperature above 1000° C., plays no important part in heat transfer.

Performance of a Baum-Type Coal-Washing Jig. H. F. Yancey and M. R. Geer. (United States Bureau of Mines, 1938, Report of Investigations 3371). A description is given of a Baum-type coal-washing jig installed at the Roslyn-Cascade Coal Co., Ronald, Eastern Washington, and the results of an investigation of the performance of this unit operating on coal from the No. 1 Mine of this company are discussed. Data are presented in tabular form.

Performance of a Pulsator-Type Coal-Washing Jig. H. F. Yancey, M. R. Geer and R. E. Shinkoskey. (United States Bureau of Mines, 1938, Report of Investigations 3372). The results of an investigation of the performance of a pulsator-type coal-washing jig operating on coal from the No. 3 Mine of the North-Western Improvement Co., Ronald, Eastern Washington, are discussed. The jig referred to is of the type recently developed by G. A. Vissac, and in principle is similar to the ore-dressing jig developed by Richards many years ago. A detailed description of the machine is not given. Data are in tabular form.

Industrial Experience with the Krämer Mill-Firing System in Coal-Mine Power Plants. F. Spruth. (Glückauf, 1938, vol. 74, Mar. 5, pp. 193–203). An account is presented of the Krämer pulveriser firing system, reference being made, *inter alia*, to the utilisation of low-grade fuels and to the attempts being made to recover the 10–15% of iron oxide contained in the flue dust. Magnetic concentration has so far proved uneconomical.

Recent Types of Presses for the Briquetting of Coal. C. Berthelot. (Génie Civil, 1938, vol. 112, Mar. 12, pp. 221–225). The author describes the construction and operation of some recent types of presses for the briquetting of coal and lignite; among those referred to is the Couffinhal-Chaléassière press which is dealt with in detail. To improve the service life of the presses the use of nickel-chromium steel for parts subjected to abrasion is referred to.

Carbonisation of Typical Bituminous Coals. Effect of Rate of Heating and Final Maximum Temperature. W. B. Warren. (Industrial and Engineering Chemistry, 1938, vol. 30, Feb., pp. 136–141). The effects are reported of the variation of the final maximum temperature from 540° to 1000° C., and of the rate of heating from 1·4° to 21·8° C. per min. on the compositions and magnitudes of the yields of products and on the hardness of cokes produced by the carbonisation of three coals of similar type and of increasing rank and of one coal of intermediate rank but of a different type. In the

case of two coals it is demonstrated that the greater part of the changes in the magnitudes of the yields with variation in the rate of heating is related to the rate of heating through a limited temperature range which has been named the " sensitive range "; this range lies wholly or in part below the plastic ranges of the coals in question. A theory of the mechanism of carbonisation based on these observations is advanced.

Development of By-Product Coking. G. W. J. Bradley and G. E. Foxwell. (Institute of Fuel, Mar. 17, 1938: Iron and Coal Trades Review, 1938, vol. 136, Mar. 18, pp. 473–474). The authors review the development of the coking industry at steelworks and point out that the industry is tending more and more to divide into two sections, one connected with the iron and steel groups and the other purely with the collieries. The tendency is, therefore, for the iron and steel works to develop into an entirely self-contained unit in which all the fuel used is derived from the coal put into the coke-ovens. Coke research and the economics of coking are discussed, and future developments considered.

Revolving-Grate Gas Producers with a High Throughput for Gasifying Lignite Briquettes. (Demag News, 1938, vol. 12, A, Jan., pp. 1–6). The general requirements of gas producers regarding design in relation to the fuel to be utilised are briefly considered and a detailed description is then given of a producer (one of six installed at a glassworks in Jena) for gasifying lignite briquettes. These producers incorporate, in addition to the central grate at the bottom, an annular grate at the base of the shaft which allows air for gasification to enter the shaft from the side. Specially designed tubular cooling jackets are also fitted, together with electrically-operated mechanical pokers. The operation and output characteristics of the producer are dealt with and the calorific value of the gas and running costs are also considered. Data are presented in tabular form. The new producers are of high capacity and very adaptable to fluctuating demands; the tar yield is also high and of a marketable quality.

The Application of Cyclone Cleaners for the Pre-cleaning of Blast-Furnace Gas. C. Popp. (Stahl und Eisen, 1938, vol. 58, Mar. 3, pp. 224–231). The author discusses the design of cyclone gas cleaners and in particular differentiates between two groups characterised by varying modes of gas ingress and egress. With suitable design and provision for removing coarser dust by gravity, the walls of the cleaner have been found to undergo no serious damage due to abrasion. The total dust-recovery figures are not the sole criterion of the efficiency of the cleaner, which must be so designed that, given an incoming gas at low temperature, the finest particles of dust may be separated. Some consideration is devoted to the problems involved in dealing with varying quantities of gas and with the question of providing the required number of cleaners to handle given amounts.

Cyclone Dust Precipitators for Blast-Furnace Gas. (Iron and Coal Trades Review, 1938, vol. 136, Mar. 18, pp. 480–481). A somewhat condensed English version is presented of the paper by Popp. (*See* p. 305 A).

Some Applications of Electrical Precipitation to Industrial Effluent Gases. H. J. Bush. (Institution of Chemical Engineers, Feb. 18, 1938). After a brief description of the early applications of the electrical precipitation method for recovering solid or liquid particles from the effluent gases from industrial furnaces and of the principle upon which it operates, the author discusses current industrial applications, the influence of particle size, features of plants at present in operation, installations for the recovery of valuable material, and installations for cleaning gas for subsequent use (reference is made under this head to the cleaning of blast-furnace and coke-oven gas).

Use of Limonite from Saint-Gervais-sur-Mare (Mérault) for Treating Chlorosis in Plants and as a Purifying Medium for Gas. (Génie Civil, 1938, vol. 112, Feb. 26, p. 193). The use of limonite from Saint-Gervais-sur-Mare, containing 68·17% of ferric oxide, 0·94% of manganese dioxide, 13·14% of silica, 5·94% of alumina, 0·69% of barium sulphate, 0·253% of sulphur, 0·195% of phosphorus and 10% of combustible and volatile matter for purifying coke-oven gas is noted. It is a high-grade limonite and is said to yield excellent results for this purpose.

Bases for the Increased Use of Blast-Furnace Gas in Ironworks. A. Schack. (Stahl und Eisen, 1938, vol. 58, Feb. 17, pp. 157–165). The increased quantities of low-grade ores being smelted in Germany have resulted in an increased output of blast-furnace gas and hence in the necessity of utilising greater quantities in the iron-working industries. This has involved the conversion of existing reheating furnaces to types suitable for firing with the gas. The thermal and combustion properties of blast-furnace gas are such that without preheating the air or the gas itself before burning in the furnace, the charge cannot be raised to rolling heat. The air is preferably preheated to 700° C., and, if possible, the gas is pre-heated also, thereby increasing its thermal effectiveness and allowing for any decrease in calorific value or increase in moisture content. The additional cost of converting furnaces to blast-furnace-gas firing can normally be recovered in one to three years by reason of the fuel economy effected. On large furnaces the low calorific value of the gas necessitates the use of more efficient burners. It has been found in this connection that neither burners with premixing devices nor those which give a mixture of air and gas in the combustion space itself adequately fulfil the requirements necessary when dealing with large quantities of gas; a really satisfactory burner for the purpose has not yet been developed. Some reference is made as to the reasons why metal recuperators are finding increased favour.

Natural Gas in the Open Hearth. R. Vaill. (Iron Age, 1938, vol. 141, Mar. 3, pp. 34–36). The author considers the use of natural gas as a fuel in the open-hearth furnace. It is shown that reasonable results are obtained by its use with both luminous and non-luminous flames but that in the latter case it is difficult to maintain the full heat input at certain parts of the heat cycle. The problem of obtaining a luminous flame from natural gas is discussed and reference is made to Boynton's patent (U.S. Patent 1942682) for rendering the gas luminous. Various types of furnace are discussed in relation to the efficient use of natural gas.

Firing Open-Hearth Furnaces. Carburetting Coke-Oven Gas with Coal Pitch and Tar Oil. (Iron and Coal Trades Review, 1938, vol. 136, Mar. 4, pp. 393–394). A slightly abridged translation is presented of an article which appeared originally in Stahl und Eisen, 1937, vol. 57, Dec. 30, pp. 1449–1452. (*See* following abstract, also p. 177 A).

The Carburetting with Pitch, With or Without the Addition of Tar Oil, of Coke-Oven Gas Employed for Heating the Open-Hearth Furnace. (Génie Civil, 1938, vol. 112, Mar. 19, pp. 254–255). An account is given of open-hearth firing practice employing coke-oven gas carburetted with pitch, both with and without tar oil, at the Thyssen Steelworks, Duisburg, the Völklingen Steelworks, the steelworks of the Bochumer Verein, the Mannesmann Steelworks at Gelsenkirchen, and at the Friedrich-Wilhelm Steelworks, Mülheim. (*See* p. 177 A).

Hydrogenation—A Review of the Early Difficulties. C. H. Lander. (Proceedings of the South Wales Institute of Engineers, 1938, vol. 53, Mar. 9, pp. 424–447). The author discusses the development of the hydrogenation process as applied to coal by Bergius, its adaptation on a commercial scale, troubles encountered with equipment, and the results obtained on numerous coals. Some references are made to the physical and chemical characteristics of coal in relation to the process.

The Utilisation of Coal with Particular Reference to the Production of Oil. C. Legrand and M. Simonovitch. (Publications de l'Association des Ingénieurs de l'École de Mines de Mons : Fuel in Science and Practice, 1938, vol. 17, Feb., pp. 41–47). The authors continue their discussion on the economic significance of the commercial exploitation of the coal-hydrogenation process. (*See* p. 239 A).

Theory of Fuel-Oil Burners. A. Delaby. (VIII^{e} Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 114–119). The author discusses equipment for atomising fuel oil and the essential functions of such plant.

PRODUCTION OF IRON

(Continued from pp. 240 A–243 A)

Swedish Iron and Steel Production—III. New Plant. D. D. Howat. (Iron and Steel Industry, 1938, vol. 11, Feb., pp. 159–164). A continuation of a previous article. (*See* pp. 116 A, 178 A). The author reviews the development of the Stora Kopparbergs Bergslags A.B., and in particular outlines the history of the company's iron works at Svartnas, which were founded in 1734. The Soderfors and Domnarvet iron and steel plants are also referred to. The ore resources of the company, ore-treating plant and smelting procedure are dealt with and new rolling-mill equipment installed at Domnarvet is noted. Owing to the increased cost and the difficulty of obtaining sufficient supplies of charcoal for the electric blast-furnaces, attempts have been made to work the old type 6-electrode blast-furnace with coke, but have not been very satisfactory. The Spigerverk (Tysland-Hole) furnace designed to use coke and coke breeze as fuel and operating on 3-phase current at voltages up to 160 between the electrodes and with a power factor of 0·8–0·9, possesses many advantages which are enumerated. A plant of this type is under construction at Domnarvet. An account is also given of the plant and production of the Hagfors iron and steel concern which manufactures, among other steels, stainless and corrosion-resisting steels, tool steels and ferro-chromium. The Brukskoncernen A.B., a holding company in which five iron and steel producing firms are incorporated is also referred to.

Elliptical Blast-Furnaces. (Stahl und Eisen, 1938, vol. 58, Feb. 24, p. 205). A summary is presented in German of an article by Pavlov which appeared originally in Stal, 1936, No. 11, pp. 1–14. Blast-furnaces of elliptical or rectangular section, known as Raschette furnaces, were introduced about 1860 and at the time found considerable use in Germany. It appears that such a furnace is still in use at the Terplogorsk Iron Works in the Urals. In this locality wooden blowing machines of low blast output were used and it is assumed that the elliptical furnace was adopted because under these conditions it gave better yields. Similar types at other Russian ironworks are referred to; it is noted that experience rapidly proved that the elliptical form conferred no special advantages either in ease of construction or in decreased fuel consumption or increased capacity. The work of Ssokolov, who more recently suggested the use of large blast-furnaces of elliptical section, and that of Skinder, who reported that the rectangular blast-furnaces in the Urals were generally unsatisfactory in operation, are referred to. Pavlov considers the elliptical form as being based upon unsound principles; the furnace at Nishny-Salda, which was built by Groume-Grjimailo, was found

after fifteen years to have assumed an almost circular interior form. (*See also* p. 115 A).

Machine-Cast Iron. J. C. Jones. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Feb. 24, pp. 178–180: Iron and Coal Trades Review, 1938, vol. 136, Mar. 11, pp. 433–435). The author describes briefly the development of the modern pig-casting machine and considers at some length the advantages of machine casting as opposed to casting in sand-moulded pig beds. The casting machines used at the Workington branch of the United Steel Companies are described in detail.

Blast Furnace and Raw Materials Development. T. L. Joseph. (Blast Furnace and Steel Plant, 1938, vol. 26, Jan., pp. 47–52). The author presents a general review of problems and developments in connection with blast-furnace practice and the winning, beneficiation and smelting of iron ores of different types. Reference is made to the treatment of wash ores in which the silica occurs mainly as a sand of less than 100 mesh size, to the methods of utilising Eastern magnetites, the crushing and sizing of ore in the Alabama district, the evaluation of blast-furnace coke, and, in connection with smelting and melting practice, to the analysis of hot metal for use in the open-hearth furnace, the desulphurisation of hot metal outside the blast-furnace, the operation of a blast-furnace at high internal pressure, a new design of pig-casting machine and new types of gas washers and auxiliary equipment.

Lean Ores. W. A. Haven. (Eastern States Blast Furnace and Coke Oven Association, Feb. 11, 1938: Steel, 1938, vol. 102, Feb. 28, pp. 48–53; Mar. 7, pp. 72–77). A detailed description is given of the blast-furnace plant of the Appleby-Frodingham Steel Co., Ltd., Scunthorpe. The plant is designed to smelt Frodingham ironstone which contains less than 25% of iron.

Smelting Lean German Ores using an Acid Burden. (Iron and Steel Industry, 1938, vol. 11, Feb., p. 172). An abridged translation into English is presented of an article by Lennings which appeared originally in Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1938, vol. 6, Jan., pp. 1–24. (*See* p. 240 A).

The Utilisation of Low-Grade Iron-Bearing Minerals in Germany. (Génie Civil, 1938, vol. 112, Feb. 26, p. 195). A summary in French is presented of an article from Metall und Erz, Dec. 1, 1937, dealing with methods for the enrichment and smelting of low-grade German iron ores, some of which contain only 25% of iron. In particular the high-silica Salzgitter ores and the Siegerland carbonate ores are referred to. Analytical data are presented.

The Utilisation of Blast-Furnace Flue Dust in Blast-Furnace Operation. E. Kayenburg. (Stahl und Eisen, 1938, vol. 58, Mar. 10, pp. 276–279). The smelting of finely-divided ores entails the production of an increased amount of flue dust which cannot readily or economically be treated again by the normal smelting technique.

The dust-injection method of Heskamp, however, enables dust and fine ore to be introduced into the lower part of the blast-furnace. A dust-recovering plant consisting of a dust-catcher, cyclone cleaner and tortuous flue is described which avoids the necessity for long dust flues, simplifies the operation of the plant and enables dust to be removed at any point in the gas main.

An Experimental Enquiry into the Interactions of Gases and Ore in the Blast-Furnace. Part V.—The Influences of Hydrogen and Steam at 450–850° C. W. A. Bone, H. L. Saunders and H. J. Tress. (Iron and Steel Institute, May, 1938; this Journal, p. 85 P). The two main reactions occurring in the blast-furnace are (1) the catalytic decomposition of carbonic oxide, $2CO \rightarrow C + CO_2$, at about 450° C. resulting in the deposition of carbon within and around the ore, and (2) the reduction of the oxides of iron, $Fe_xO_y + CO \rightarrow Fe_xO_{y-1} + CO_2$, at higher temperatures. Data have been given in previous communications of the relative velocities of these reactions under varying conditions of temperature, CO_2 concentration, speed of gas flow, and degree of reduction of the ore, referred in all cases to a state of $CaCl_2$-dryness in the gas phase. Relative velocity measurements have now been extended to include the effects produced by additions of up to 2% of hydrogen and steam to blast-furnace gas over a temperature range of 450° to 850° C. The results show that both hydrogen and steam accelerate carbon deposition. Hydrogen also accelerates ore reduction, whilst the influence of steam is less definite.

Catalysts for Bell's Reaction ($2CO \rightarrow CO_2 + C$). G. I. Chufarov and A. N. Kulikov. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 3–7). (In Russian). The authors investigated the catalytic decomposition of carbon monoxide by iron prepared from ferric oxide by reduction in hydrogen at 300° C. and by ferrous oxide prepared by oxidising metallic iron with water vapour and hydrogen at 900° C. The variations in the pressure of a constant volume of carbon monoxide circulated over the catalysts at 400–500° C. were determined. Ferrous oxide has not been found to promote the decomposition of carbon monoxide, but iron has a strong effect, until its surface becomes covered with ferroso-ferric oxide produced by the oxidising action of carbon dioxide, when the reaction ceases.

Formation of Primary Slags in Blast-Furnaces. M. Y. Ostroukhov. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 38–46). (In Russian). The author presents tabular data respecting the composition and melting points of eutectics with the lowest melting points in the binary and ternary systems containing silica with one or more of the following: Alumina, lime, magnesia and ferrous oxide, in the presence of silicates of potassium, sodium, calcium or manganese. It is suggested that the first slag formed by melting a synthetic mixture of oxides or silicates consists of the lowest-melting-point eutectic of the corresponding system. But such eutectics are not necessarily the most fluid melts, hence the really fluid slags which eventually appear may have a different composition from the

first liquid phase formed. The author discusses the analyses of the primary slags produced in different zones of the blast-furnace as determined by Bohn, Kinney and others.

Temperature of Formation of Globules of Primary Blast-Furnace Slags. M. Y. Ostroukhov. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 80–90). The downward movement of slags in blast-furnaces is determined not only by the relative viscosity of different types of slag but also by their capacity to form globules and detach themselves from the surface of the ore. The author discusses the results of a detailed investigation in which the temperatures at which a number of salts, including alkaline and alkaline-earth chlorides, form droplets were determined in order to test the efficacy of the experimental technique adopted (these results are compared with data derived by other investigators), together with the temperatures of droplet-formation of silica/alumina/lime, silica/lime/ferric-oxide, and silica/ferric-oxide mixtures as well as a number of blast-furnace slags. Drops are formed in the first ternary system mentioned at 1395° C. by a mixture of a composition approximating to that of the 1265° C. eutectic, but mixtures with a composition approximating to that of the lowest eutectic (1170° C.) form globules only above 1450° C., hence slags of this composition can only detach themselves from the ore by changing their composition and attaining a fluid state. The addition of 5% of magnesia or of a small quantity of ferric oxide decreases the temperature of drop formation. Actual slags investigated behaved analogously to the quaternary system silica/alumina/lime/magnesia.

A Decade of Iron and Steel in Canada. A. W. G. Wilson and J. Casey. (Transactions of the Canadian Institute of Mining and Metallurgy, 1938, vol. 41, pp. 89–102). The authors present a survey of the Canadian iron and steel industry for the last decade from the technical and economic standpoints. Tabular data are presented.

Le Creusot in 1794. A. Daubois. (Arts et Métiers, 1937, vol. 91, Dec., pp. 265–270). An account is given of the plant, raw materials and operating methods at the Creusot works (France) in 1794. Reference is made to fuel resources (coal) and to the lining of the blast-furnaces.

FOUNDRY PRACTICE

(Continued from pp. 244 A–247 A)

A Novel Development in Melting Practice. V. C. Faulkner. (Foundry Trade Journal, 1938, vol. 58, Mar. 17, pp. 235–236). An account is given of the construction and operation of the Walbro cupola which is differentiated from other types of cupola in possessing a centrally disposed hole which is never closed in place of the normal tapping spout. A special receiver is used in conjunction with the cupola, which is ideally suited for the provision of small quantities of metal for continuous production. Carbon and sulphur pick-up is abnormally low, and the temperature of the metal as tapped is considerably higher than usual. Special attention is devoted to moulding and casting practice employed in conjunction with the Walbro cupola.

Standardise your Cupola Practice. G. P. Phillips. (Northern Iowa Foundrymen's Association and American Foundrymen's Association: Foundry, 1938, vol. 66, Feb., pp. 28–30, 71). The author considers in detail the preparation of the cupola prior to charging, the procedure for blowing-in, the nature of the charge and the charging operation, tapping and the control of combustion.

Behaviour of Coke in the Foundry Shaft Furnace. G. Speckhardt. (Giesserei, 1938, vol. 25, Feb. 11, pp. 55–58). The author presents a review of the results of theoretical studies of the reactivity of coke in the cupola and discusses their significance from the standpoint of cupola operation in practice. In particular the effect of such factors as the size of the coke, cupola design and air input are dealt with at length.

Melting Scrap in the Cupola. E. Piwowarsky and K. Achenbach. (Technische Hochschule, Aachen: Giesserei, 1938, vol. 25, Feb. 25, pp. 74–80). It is shown that massive iron is not carburised, but rather decarburised, by gases in the cupola shaft; cementation by the coke present occurs only to a very limited degree. Steel melts as such and takes up carbon only in the cupola hearth. Factors influencing carburisation are discussed at length and it is shown that for the melting of high-steel mixtures no more heat (and, therefore, no greater coke consumption) is required than for melting steel-free or low-steel mixtures. The chemistry of the reactions occurring in the cupola is discussed from the physical standpoint, and the reactions between the coke and blast at the higher temperatures necessary to melt steel are indicated; a method is explained whereby the pig or cast-iron scrap in the charge may be strongly superheated in the molten state before it reaches the hearth.

Melting of Cast Iron in the Foundry. S. E. Dawson. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58,

Mar. 10, pp. 219—221). The selection of an appropriate furnace for melting various grades of cast iron is not entirely controlled by the cost of melting but may be influenced by the type of metal concerned and the tonnage and the rate of supply required. Tabular data are presented regarding melting costs for cupolas, crucible furnaces, oil- and coal-fired rotary furnaces and the electric furnace, the structural and operating characteristics of each of these types being then discussed in detail. In particular, fuel consumption and the life of linings are considered. Changes in the composition of the irons during melting and rates of melting are also dealt with.

Influence of Preliminary Treatment on the Graphitisation of Whiteheart Malleable Cast Iron in Malleablising. G. N. Trotzky and I. S. Kvater. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 66–74). (In Russian). The authors discuss the results of attempts to decrease the time of annealing by increasing artificially the number of nuclei for the crystallisation of graphite. These are formed at the cementite-austenite boundaries and their formation is favoured by heat treatment (normalising, quenching, or rapid heating by electrical methods). Normalisation gives little effect, but quenching in oil from 930° C. reduces the annealing time to 15 hr. and this method can be applied to castings of small section and simple shape. Water-quenching reduces the annealing time to 9–10 hr., but, owing to the danger of the castings cracking, cannot be used in practice. The decrease in size and increase in number of graphite flakes produced by these treatments result in no changes in the mechanical properties of the material.

Observations on Moulding and Casting Practice in the Steel Foundry. Singer. (Giesserei, 1938, vol. 25, Feb. 25, pp. 85–88). The author discusses the effect of moulding technique, the purpose for which the casting is designed, and the arrangement of the pattern on the methods of producing a steel casting. Flaws in steel castings are dealt with. Certain modifications in moulding and casting technique are suggested.

Foundry Sand Control. R. F. Harrington. (Canadian Metals and Metallurgical Industries, 1938, vol. 1, Feb., pp. 58–60). The author discusses the physical characteristics of moulding sand and refers specially to the development of standard tests by the American Foundrymen's Association.

Controls Molding Sand Properties. W. G. Reichert. (New England Regional Foundry Conference, Massachusetts Institute of Technology: Foundry, 1938, vol. 66, Feb., pp. 36–37, 80, 83). (*See* p. 245 A).

Feeding of Castings with Special Reference to the Steam Pressure Method. B. Hird. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Mar. 3, pp. 195–196). After a preliminary discussion on defects caused in castings by liquid shrinkage and on methods adapted to overcome the difficulties due to shrinkage, the author deals first with rod feeding, the various practices adopted

for this being briefly described and the general disadvantages of the system as a whole being pointed out. Pressure feeding and in particular steam-pressure feeding are then considered in detail. Precautions to be taken when applying this method are noted and certain successful applications of steam-pressure feeding ar referred to.

Core Drying Ovens. Examples of Current American Practice. (Foundry Trade Journal, 1938, vol. 58, Mar. 3, p. 201). The thermal characteristics of core-drying ovens are considered and brief reference is made to problems in connection with fuel-consumption data. The construction and operating characteristics of the vertical conveyor oven are discussed at some length.

Rams Large Molds on a Machine. P. Dwyer. (Foundry, 1938, vol. 66, Feb., pp. 24–26, 66, 68). An account is given of the machine ramming of moulds for machine beds at the Cooper-Bessemer Corp. foundry plant at Mount Vernon, Ohio. The total weight of the moulds, ready for the drying oven, is approximately 57 tons. The moulding procedure is described in detail.

Some Aspects of Heavy Castings. E. Longden. (Institute of British Foundrymen: Foundry Trade Journal, 1938, vol. 58, Feb. 24, pp. 183–186; Mar. 3, pp. 199–200). In the first part of the article the author discusses the equipment and tackle for heavy casting production, the moulding of a 17-ton caustic pot, the moulding of a 21-ton, 51-in. gun-tube boring-machine spindle, the moulding of a 32-ton, 94-in. lathe headstock, the moulding of a 50-ton hammer-anvil block, suitable metal for large castings and the influence of design on contraction and distortion. In the second section the author discusses the optimum compositions of cast irons for large castings, the control of microstructure and the influence of various elements upon it, and the minimising of variables as exemplified in the moulding and casting procedure adopted for an experimental stepped casting.

Cast Tools. S. A. Kazeev and L. P. Ermoshkin. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 78–85). (In Russian). The authors describe the successful production of milling cutters by casting them in steels containing carbon 0·72–1·90%, chromium 4·6–15·17%, vanadium 0·15–0·49% and tungsten 1·62–19·39%. The techniques of moulding, melting and casting are described.

Exhaust Requirements for Foundry Dust Control. J. M. Kane. (Foundry, 1938, vol. 66, Feb., pp. 31, 72, 74). The author discusses the dimensions of exhaust-system units and the corresponding volumes and velocities of exhaust air required by different departments in the foundry. The relative dust concentrations for different sections of the foundry are presented and compared; upon these data the dimensions of exhauster pipes and the characteristics of the exhaust air depend. (*See* p. 246 A).

Stove Shop is Equipped Mechanically. (Foundry, 1938, vol. 66, Feb., pp. 32–34, 77). An account is given of the mechanised

foundry at the Marshall Stove Co., Lewisburg, Tenn. The sand-preparation system conditions and conveys 90 tons of sand per hr. The rapid turnover necessitated some means of keeping the sand cool; this was achieved by carrying it on slow-moving conveyors from the shake-out to a storage bin of 130 tons capacity. The layout of the foundry is discussed at length.

A Cultural Monument of Foundry Technique. W. Hartung. (Giesserei, 1938, vol. 25, Feb. 11, pp. 58–59). An historical account is given of the blast-furnaces and foundry at the Louise Iron Works, Wocklum, Arnsberg (Westphalia). Details of the plant, which is still in almost perfect condition, are given. In its existing form this dates from about the middle of the nineteenth century.

Contraction Stresses in Castings. Methods of Stress Relief. W. Machin. (Iron and Steel Industry, 1938, vol. 11, Feb., pp. 173–177). The author discusses the cracking of cast iron due to the interference with contraction caused by cores and moulds of too heavy a construction. The results of experiments to indicate the effects of such interference are discussed and the conditions best suited to the obtaining of normal contraction movements dealt with. Attention is directed to the influence of runner distribution and of the anchoring of runners and risers due to the sand adjacent to them not being eased. The results of an investigation on casting strains in a cast-iron wheel cast in a dry-sand mould are discussed in detail. It is shown that careful heat treatment of castings is essential where it is considered necessary that contraction stresses should be removed.

Viscosity, Surface Tension and Castability in Metallurgy and, more particularly, in Founding. P. Bastien. (Bulletin de l'Association Technique de Fonderie, Sept., 1937). The author considers briefly the physical properties denoted by the terms viscosity, surface tension and castability and then discusses each quality in greater detail and examines its influence on other properties such as rates of diffusion and reaction; the reactions occurring in the basic open-hearth furnace are discussed in the light of these considerations. The selection of fluxes is also dealt with from a similar standpoint. Methods of measuring viscosity are considered. Surface tension is described and phenomena occasioned by this property are dealt with, including differences in the rate of carbon elimination in the manufacture of steel. In particular the casting properties of metals are considered from the standpoint of the physical properties previously referred to.

PRODUCTION OF STEEL

(Continued from pp. 248 A–250 A)

Allegheny Steel Company. Makers of Alloy Steel. C. Longenecker. (Blast Furnace and Steel Plant, 1938, vol. 26, Jan., pp. 84–90, 111–112, 114, 119; Feb., pp. 186–187, 192). An account is given of the formation of the Allegheny Steel Company and of its subsequent development and organisation into its present form. The company has two manufacturing plants, one at Brackenridge and one at Leechburg. The former plant consists of the following units: Electric furnace department, open-hearth department, blooming-mill department, strip mill, sheet mill, merchant mill, plate mill, tube mill, seamless tube department, steel castings department, iron castings department and lamination and stamping department. Each of these units is described in detail, operating conditions, plant and production being noted. Reference is made, *inter alia*, to an education system sponsored by the company in which specialised and general subjects are dealt with for the benefit of younger employees. The Leechburg Steel and Tinplate Company produces high-grade strip from 0·5 to 24 in. wide; a full description is given of the equipment of this section of the Allegheny Steel Company's plant.

Fifty Rules for the Treatment and Handling of Graphite Crucibles. E. R. Thews. (Canadian Metals and Metallurgical Industries, 1938, vol. 1, Feb., pp. 44–47). The author outlines the principal precautions to be observed in the use of graphite crucibles for metal melting; in particular the procedure for handling them during the actual melting operation is dealt with.

Improvement in Open-Hearth Furnace Efficiency. A. Smithson. (Metallurgia, 1938, vol. 17, Feb., pp. 111–115). The use of control systems as a means of increasing the efficiency of the open-hearth furnace is considered and reversal control, roof-temperature control, furnace-pressure control and combustion control are each discussed in detail, various instruments for each purpose being dealt with.

Metallurgical Investigation of a Mixer. L. P. Vladimirov and M. S. Spirodonov. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 22–37). (In Russian). A detailed report is presented of results obtained at the Kuznetzk Works (Siberia) with a 1200-ton mixer for homogenising pig iron. Data are presented in graphical and tabular form and deal mainly with the degree of chemical homogeneity of the melt.

Symposium on Steelmaking. (Iron and Steel Institute, May, 1938, Special Report No. 22). At this Symposium papers were presented, on acid and basic open-hearth practice at representative steelworks in various districts of Great Britain, the physical chemistry

of steelmaking, and the correlation of British open-hearth data. The following is a complete list of the papers : " Basic Open-Hearth Practice in Scotland," by J. G. Fairgrieve and J. Gibson; " Manufacture of Plain Carbon Acid Steels," by J. M. Ferguson; " Some Aspects of Slag Control in Melting Practice," by R. Hay, J. M. Ferguson and J. White; " Open-Hearth Steelmaking as Practised at the Irlam Works of the Lancashire Steel Corporation, Ltd.," by J. Sinclair Kerr, J. V. Morgan, W. Goldsbrough and D. Binnie; " The Barrow Hæmatite Steel Company, Ltd.," by J. W. Danks and V. W. Davison; " The Steel Plants of the Frodingham District, Scunthorpe, Lincolnshire," by J. B. R. Brooke, S. R. Isaac and A. Robinson; " The Appleby-Frodingham Steel Company's Melting Shops," by A. Robinson; " John Lysaght, Ltd., Normanby Park Steel Works, Scunthorpe," by J. B. R. Brooke; " The Redbourn Works Melting Shop of Messrs. Richard Thomas & Co., Ltd.," by S. R. Isaac; " Acid and Basic Open-Hearth Practice on the North-East Coast," by Frank Bainbridge, W. Geary, James Winter and P. W. Wood; " Practice at the Works of the South Durham Steel and Iron Co., Ltd., and Cargo Fleet Iron Co., Ltd.," by James Winter; " Open-Hearth Acid and Basic Processes at Consett," by P. W. Wood; " Plant and Practice at Works of Messrs. Dorman, Long & Co., Ltd.," by W. Geary, L. E. Crooks and E. Drewery; " The Melting Shop of the Skinningrove Iron Co., Ltd.," by Frank Bainbridge; " Acid Siemens Open-Hearth Process," by E. Dawtry, W. H. Hatfield, and C. W. Wright; " Making Basic Open-Hearth Steel for Many Purposes," by R. Percival Smith; " Basic Open-Hearth Steelmaking Practice of the Park Gate Iron and Steel Co., Ltd., Rotherham," by R. T. Lintern and R. A. Hacking; " Some Experiences in the Design and Control of Open-Hearth Furnaces," by R. J. Sarjant and E. J. Barnes; " Steelworks Refractories," by T. Swinden and J. H. Chesters; " The Mixed-Gas Melting Shop of Guest Keen Baldwins, East Moors, Cardiff," by James A. Davies; " A Tilting Furnace Fired with Cold Coke-Oven Gas," by R. W. Evans; " The Application of Physical Chemistry to Steelmaking," by A. McCance; " British Open-Hearth Data and their Correlation," by the Open-Hearth Committee of the Iron and Steel Industrial Research Council. A bibliography on the physical chemistry of the open-hearth process, covering the period 1920–1937 is also included.

Refining of Pig Iron and Ferro-Manganese for the Production of Carbon Steel by the Acid Process. G. L. Sakharov. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 66–79). (In Russian). The author describes in detail the methods of removing phosphorus, sulphur and, to some extent, carbon from the materials used in the production of high-grade acid steel. Special reference is made to conditions prevailing in the charcoal blast-furnaces in the Urals and those in the Donetz Basin operating with a high-sulphur coke. Until recently high-grade steel in the U.S.S.R. was produced from low-sulphur,

low-phosphorus Satkinsky pig iron, but the ores from which this was produced have deteriorated and it has been found necessary to use refined pig produced from less pure ores. Thermal and other data are presented in tabular form.

Contribution to the Question of the Behaviour of Nitrogen and Hydrogen During Melting in the Open-Hearth Furnace. C. Schwarz. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 355–362). As a result of his experiments the author concludes that the hydrogen content of samples of steel is independent of the process employed for melting it. In so far as rate of loss of nitrogen is concerned, the relationship between this value and the value for the velocity of decarburisation is well recognised in the case of the duplex process, but no such connection has been determined for other processes characterised by lower nitrogen absorption. Theoretical considerations of the conditions governing the absorption of gas by the steel from the fuel gases indicate the lines for future research on the behaviour of nitrogen and hydrogen during the production of steel.

Experimental Investigations on the Mineralogical Composition and on the Chemical Action of Slags Produced in Steelmaking. W. J. Crook. (Thesis, École Polytechnique Roi Carol II., Bucharest, 1936). The author discusses in his preliminary sections the present state of knowledge on the constitution of slags and the purpose of his investigations. The general rôle of slags, their classification on the basis of degrees of acidity and the fundamental error of this system, methods and difficulties of investigating slags, the states of oxidation of iron in slags, influence of the presence of oxygen, the quaternary system $SiO_2/FeO/Fe_2O_3/CaO$, and the common features of all steelmaking processes are discussed in an introductory chapter. Subsequent chapters deal with the preparation of synthetic slags, their chemical analysis, microscopic examination, equilibria between the oxides of iron in slags, the mineralogical composition of the slags investigated, the equilibrium diagram of the $FeO/SiO_2/Fe_2O_3/CaO$ system and chemical reactions taking place in this system as deduced from the diagram, studies of reactions occurring in the quasi-quaternary systems, the chemical action of slags in steelmaking, and an examination of different processes for the manufacture of steel.

Solidification in Open-Topped and Closed-Topped Ingot Moulds. B. Matuschka. (Iron and Steel Institute, May, 1938; this Journal, p. 109 P). The author first discusses certain factors which exert a profound influence on the piping of steel ingots; the influence of casting temperature and of the ratio of the ingot weight to that of the ingot mould are considered at length. Graphical data are presented with respect to the momentary volumes of solidified steel, to momentary heat loss and to the course of solidification in ingots of different diameters. It is demonstrated that freezing and piping proceed rapidly both at the commencement and shortly before the

completion of the solidification process. The relative importance of the decrease in volume of the steel on cooling down to the freezing point, of the shrinkage on transition from the liquid to the solid state and of the contraction on cooling down to room temperature are also discussed in connection with the degree of piping.

In dealing with the mechanism of piping, it is stated that piping originates from and presupposes a contractile process in the liquid or solid part of the ingot. The effect of thermal contraction phenomena in the ingot upon the formation of the pipe are considered with particular reference to the influence of the shrinkage of the frozen ingot skin upon the course of solidification of the still molten interior of the ingot. Explanations are advanced, based on the interference introduced into the normal thermal contraction of the molten steel by the mechanical and physical influence of the solidified ingot skin and by the ferrostatic pressure of the molten metal, for certain structural peculiarities and for the occurrence, under given conditions, of gas evolution and the formation of blow-holes. By consideration of the motion of the molten metal contained within the ingot skin during the progress of solidification, simple explanations are educed for the well defined and sudden transition from a columnar zone to a zone of small equiaxed crystals and for the inclined position of the segregates at the ingot rim—the so-called L-segregates. The effect of ingot shape upon the characteristics of segregation and of blow-hole formation is examined.

The results are discussed of an investigation carried out on ingots of a basic open-hearth steel employed for the manufacture of railway wheels, and comprising the examination of the pipe formation in ingots solidified under various conditions both as to open-topped and closed-topped ingot mould practice. It is shown that relatively slight variations of pressure exert an appreciable influence on the capacity of a steel ingot for retaining gases in solution. Solidification in open-topped moulds and the maintenance of an open pipe by means of a heat-generating medium (" Lunkerit ") assist in the production of a dense steel free from flaws. It is also demonstrated that slight decreases in pressure arising as a result of the solidification process in the body of the ingot may lead to gas evolution of a type producing abnormal piping and detracting from the quality of the steel.

On the Origin and Removal of Slag Inclusions in Basic Electric Steel. F. K. Buchholz, A. Ziegler and E. Voos. (Stahl und Eisen, 1938, vol. 58, Mar. 3, pp. 231–235). Oxide and iron-manganese-silicate inclusions originate during the refining process and a method of avoiding such inclusions by the correct choice of decarburising rate and time is indicated. In order to obtain steel free of inclusions the refining rate and its duration as well as the final carbon content before slagging off and before adding ore must be carefully controlled. A number of factors are enumerated upon which calculations must be based individually for each heat.

Crystallisation and Structure of the Ingot. V. O. Hagen-Torn. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 3–20). (In Russian). The author criticises Tammann's theory of the velocity of crystallisation in relation to the degree of undercooling. It is suggested that the self-formation of nuclei is an unnecessary assumption, a sufficient number of preformed nuclei, such as foreign particles and gas bubbles, being always present. Crystallisation occurs without appreciable undercooling, and its velocity is determined mainly by the rate of loss of heat on solidification. The solidification process in ingots is discussed with respect to both nuclei and heat conductivity. The influence of ingot shape is noted together with the effect of mechanical disturbance of the still-liquid metal in the ingot by convection and other processes. The experimental verification of the author's conclusions is described.

Distribution of the Metalloids in Rimmed-Steel Ingots. J. W. Halley and T. S. Washburn. (American Institute of Mining and Metallurgical Engineers, Technical Publication, No. 898 : Metals Technology, 1938, vol. 5, Feb., No. 2). The authors define their standard of "normality" in relation to steel. Ingots showing the greatest departure from normality retained the essential differences in distribution between carbon, manganese and sulphur. Near the top of the ingot carbon decreases across the rim, increases sharply at the secondary blow-holes and increases from these to the centre of the ingot. At half the height of the ingot the carbon decreases slightly across the rim, increases at the secondary blow-holes and is practically constant across the core zone. Near the bottom the carbon is practically constant across the ingot. Manganese decreases across the rim zone all the way round the ingot. At the top of the ingot it increases at the secondary blow-holes, but at the bottom the manganese content decreases in their vicinity. In the core zone manganese increases from top to bottom of the ingot but the increase is much smaller than that of carbon or sulphur. Sulphur is practically constant throughout the rim zone and shows a sharp increase at the secondary blow-hole zone. The increase in sulphur in the core zone between the bottom and top and between the secondary blow-hole zone at the centre of the ingot is much greater than the increase in manganese or carbon.

REHEATING FURNACES

(Continued from pp. 251 A–252 A)

Slab-Heating Furnaces at New J and L Continuous Sheet and Strip Mill. (Industrial Heating, 1938, vol. 5, Feb., pp. 140–142). An account is given of the three Rust continuous slab-heating furnaces installed at the new continuous sheet and strip mill of Jones and Laughlin, Pittsburgh, Pa. They are of the triple-fired zone-controlled type, fired with coke-gas or tar and are each rated to heat 50 tons of cold slabs per hour. Constructional and operating data are presented.

Rate of Heating of Low- and High-Alloy Steels. E. A. Klausting. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 31–42). (In Russian). The author investigated the effects of introducing cold steel ingots direct into hot furnaces. With annealed 200-kg. ingots of high-speed steel (tungsten 18%, chromium 4%, vanadium 0·7%) cracking occurred with furnace temperatures above 1150° C.; with unannealed ingots cracking occurred at a furnace temperature of 850° C. With 300-kg. ingots cracking was observed with a furnace temperature of 650° C. when the ingot had not previously been annealed. A structural steel, containing 4·3% of nickel and 1·5% of chromium, in the form of 1000-kg. ingots can be placed in a furnace at 1180–1270° C. without cracking owing to its higher thermal conductivity and elastic limit. Preliminary experiments on tool steels and special alloy steels have yielded analogous results. The Electrostal Works now places cold 1000-kg. ingots of structural steel direct into furnaces at 900° C., while unannealed high-speed-steel ingots are heated directly from 500° C.

FORGING, STAMPING AND DRAWING

(Continued from p. 253 A)

Modern Sucker Rod Manufacture. W. C. Kernahan. (Heat Treating and Forging, 1938, vol. 24, Jan., pp. 13–16). The author describes the requirements of steel for the production of " sucker rods " for deep oil-well pumps. The process of producing these components by upset forging from nickel-molybdenum steel bar stock at the Carnegie (Pa.) plant of the National Supply Company is described. The choice of steel depends largely on the conditions to be encountered. Corrosive environments, particularly the presence of hydrogen sulphide, demand the use of steels with higher nickel contents which may range from 1·65–2·0% to 3·25–3·75%. The corresponding carbon contents are 0·2–0·25% and 0·12–0·18% with a molybdenum content of 0·2–0·30%.

Forging of Light and Heavy Metals with the Hand Swage. B. Preuss. (Metallwirtschaft, 1938, vol. 17, Mar. 4, pp. 249–250). The author considers the use of hand forging in circumstances where the output would not warrant the laying down of expensive plant; the economic advantages of carrying out work of this type by hand are briefly discussed. An operation card showing the steps in the fabrication of a light forging by hand and the times occupied by each operation is presented, together with a diagrammatic representation of each step and the tools used for it.

Progress in Drop Forging. R. W. Thompson. (Heat Treating and Forging, 1938, vol. 24, Jan., pp. 9–11). The author discusses recent developments in drop-forging technique, in forging hammers and in the extended application of drop-forged components in plain and special alloy (corrosion- and heat-resistant) steels.

Time Standards for the Drop Forge Die Shop. Part III.—Die Sinking. Part IV.—Incidental Operations on Die Blocks. C. N. Harwood. (Heat Treating and Forging, 1938, vol. 24, Jan., pp. 19–25; Feb., pp. 65–70). The author continues his discussion on time standards for the drop-forge die shop. (*See* p. 253 A). The application of time studies and planning, the layout of a series of operations and rate fixing are considered in relation to die sinking and to operations involved in either the finishing of the die or the preparation of the raw material for the sinking operation.

Machine Tools for Pressing, Stamping and Forging. G. Fritz. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Feb. 26, pp. 232–240). Various modern types of forging, pressing and stamping machines of German origin are described, special attention being paid to the output capacity, accuracy of working and features responsible for greater safety of operation.

Presses and Sheet-Metal Machinery. (Iron Age, 1938, vol. 141, Jan. 6, pp. 306–312; Jan. 20, pp. 40–44). Brief descriptions are given of the chief features of interest of some of the more recently introduced designs of hydraulic and mechanical presses and sheet-metal working tools.

Mild Steel for Sheet and Strip. H. H. Stanley. (Lincolnshire Iron and Steel Institute: Iron and Coal Trades Review, 1938, vol. 136, Feb. 18, pp. 319–320). The author summarises the requirements of sheet and strip suitable for deep-drawing purposes and considers types and compositions of suitable steel. The importance of crystal size is stressed, and heat-treatment processes designed to produce the correct grain size and ductility are outlined. The interpretation of the stress-strain curve is dealt with at length and ageing phenomena are referred to together with the difficulties to which they give rise in deep-drawing. The development in America of a non-ageing steel containing relatively large quantities of deoxidising agents and hence practically no dissolved oxygen is noted. It is said that a special heat treatment is required to make this material non-ageing, namely, normalising followed by a low-temperature anneal at 650° C., the work being allowed to cool at 5–10° C. per hr.

From Ore to Wire at a Glance. W. A. Seburn and D. Neuman. (Wire and Wire Products, 1938, vol. 13, Mar., pp. 115–119). The authors give a concise description of plant of the Pittsburgh Steel Co. and of the principal processes used in wire production operations.

Production of Telegraph Wire from Armco Iron. P. A. Alexandrov and S. I. Usov. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 91–103). (In Russian). The electrical resistance of Armco-iron wire is lower than that of steel wire (0·110 ohm per sq. mm. per m.). Intermediate annealing during the drawing of Armco wire is inadvisable, owing to the possibility of free cementite being produced, and rolling should not be carried out below the upper limit of the brittle range. This latter point is further emphasised by M. Kolesnikov in the discussion appended to the paper.

ROLLING-MILL PRACTICE

(Continued from pp. 254 A–255 A)

Resistance to Deformation in Cold-Rolling. I. M. Pavlov and Y. S. Gallay. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 62–79). (In Russian). The authors determine the resistance to deformation (P) by cold-rolling from the formula

$$P = pB\sqrt{R(H-h)}$$

where p is the pressure of the metal on the rolls as found from direct measurement, B the width of the strip, R the radius of the rolls and H and h are the thickness of the strip before and after rolling. It is shown that P is independent of B for values of $B \leqq 6$ cm., and of $(H-h)$ up to a total elongation of 250–300%. Where deformation is very heavy as in the case of very thin strip, p increases hyperbolically with increasing values of $(H-h)$. Lubrication causes a marked decrease in P, the efficacy of the following lubricants rising in the order: Petrol, alkali, machine oil, castor oil. The calculation of resistance to deformation is discussed for examples both with and without lubrication and it is shown that for a given reduction the number of passes may be reduced by half if the correct lubricant is employed. Non-ferrous metals were employed for these investigations.

The Flow of Metal Between Rolls. L. Moses. (Iron and Steel Engineer, 1938, vol. 15, Feb., pp. 16–33). The author presents a comprehensive discussion on the deformation processes occasioned by the passage of various types of steel through rolls and on the individual characteristics of such deformation for particular rolling processes. The factors and conditions controlling the deformation are considered in detail.

Trends in Steel-Mill Lubrication. L. Ballard. (Blast Furnace and Steel Plant, 1938, vol. 26, Jan., pp. 56–60). The author discusses improvements which have been effected in lubricants from the standpoint of their physical, chemical and mechanical properties and refers in particular to the use of compounded oils and those containing addition agents designed to produce or enhance some special characteristic. Greases are also dealt with. It is indicated that lubrication will in future tend more to utilise the properties of "alloyed" lubricants in which refining has been carried to the most economical point and in which additional properties necessary or desirable for specific applications are obtained through the use of addition agents of various types. The advantages of sleeve-type roll-neck bearings and lubrication problems encountered in their use are also dealt with.

Lubrication. C. C. Pecu. (Steel, 1938, vol. 102, Mar. 14, pp. 50–53). The author discusses the properties and advantages of

extreme-pressure grease lubricants of low viscosity and high film strength for lubricating gears, pinions and roll necks, and deals also with the characteristics and applications of " waterproof " greases and others for special purposes, such as for use on pushers and levellers in coke-ovens, where they are exposed to high temperature. Tabular data are presented showing the applications of cup greases for rolling-mill equipment, the applications of various lubricants in blooming mills and bar mills, and the partial analysis of various greases.

Steel Mill Lubrication. H. N. Bassett. (Metallurgia, 1938, vol. 17, Feb., pp. 123–124). The author considers the lubrication of bearings of rolls, shears, saws and table rollers and discusses the relative merits of pressure and oil-bath systems and the special measures which must be adopted when neither of these systems is applicable. Particular reference is made to difficulties entailed in the lubricating of table roll bevel gears; a grease with a viscosity of 1800 sec. Redwood at 200° F. is recommended for the purpose. Roll-neck lubrication demands a grease rather than an oil, which will not be displaced by water fed to the roll necks for cooling purposes and which will not be readily carbonised at the temperatures to which it is frequently exposed—300–350° F. For lubricating the motor driving the shears a fairly light oil is required, whilst for the gears through which the drive is transmitted a lubricant similar to that used for roll gears is suggested. In conclusion various lubricating systems are discussed together with the properties of lubricants appropriate to them.

Jones and Laughlin's New 96″ Hot and Cold Strip Mill. (Iron and Steel Engineer, 1938, vol. 15, Jan., pp. J-L1–J-L17). (*See* p. 191 A).

From Open-Hearth to Cold-Rolled Strip. (Sheet Metal Industries, 1938, vol. 12, Feb., pp. 173–176). The production of strip from open-hearth steel is traced from the moment of tapping, through the stages of ingot teeming and cogging to the final pass through the finishing rolls. The practice described is that carried out at the Templeborough Works of the United Steel Companies, Ltd. Much of the output from the mills dealt with is utilised by Messrs. Samuel Fox and Co., Ltd., whose plant and production are also described in the article. In particular, reference is made to the new electric steel plant, equipped with three high-frequency furnaces, one of 2 tons and one of 5 tons capacity, and to the Grunewald bright-annealing furnace which has a capacity of 150 tons per week. Some account is given of the roll-grinding department of Messrs. Samuel Fox's Stocksbridge works, special attention being paid to the cambering devices on the grinding machines.

Cold-Rolling Strip from Round Steel Wire. M. I. Zlotnikov. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 47–61). (In Russian). The author compares the production of narrow strip from cylindrical wire by cold-rolling with the rolling of rectangular

rod. Graphs and nomograms are given for calculating the diameter of wire required to give strip of definite gauges and widths.

Progress in the Manufacture of Seamless Tubes. G. Evans. (Iron and Steel Industry, 1938, vol. 11, Feb., pp. 169–171). An account is given of a new process for the production of seamless tubes of small diameter operated by the Mannesmann Company in Germany. The tubes are extruded in a mechanically operated press at 1250° C. Tubes up to $\frac{3}{4}$ in. diameter and in lengths of 65 ft. may be produced in lower-grade steels such as basic Bessemer, or in high-grade high-alloy steels. The extrusion process is described and its advantages are enumerated.

Electrification of Rolling and Auxiliary Equipment. (Iron and Coal Trades Review, 1938, vol. 136, Jan. 7, pp. 1–2). An account is given of the electrical drives and controls for rolling-mill and auxiliary equipment at the Haybridge Steel Works, Ltd. Reference is made to the systems employed before electrification was introduced.

The Application of Time Study to Rolling Mills. (Iron and Steel Institute, 1938, Special Report No. 20). This Report, by the Rolling Mill Committee of the Iron and Steel Industrial Research Council, describes a series of investigations carried out with the idea of extending the use of time study in iron and steel works. Three mills were examined :—

(*A*) A steam-driven 36-in. cogging mill.
(*B*) An electrically-driven 36-in. cogging mill.
(*C*) An electrically-driven 30-in. slabbing mill.

By applying standards based on time studies, an efficiency index was established by means of which performances of each mill could be compared. From a study of the Report the following facts are made apparent : (1) That the application of research into problems of production control, conducted principally by means of the stop-watch, will provide reliable standards of performance and show how plant utilisation can be increased. (2) That a considerable difference was found to exist as between the best tonnage that could be produced and what was in fact turned out. (3) That time studies have brought to light the necessary requirements to secure the best output under optimum conditions and a reliable method of comparing outputs obtained from time to time, irrespective of the ingot size and finished section. No attempt, however, has been made to compare the performance of the very dissimilar mills examined.

Contribution to the Question of the Settlement of General Operating Expenses in Costing on a Time Basis. W. Grenz. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 413–416). The author discusses suggested modifications to costing systems applicable more especially to industrial concerns producing varied groups of products. Reference is made to the application of the modified system to rolling mills.

HEAT TREATMENT

(Continued from pp. 257 A–258 A)

Concerning the Diffusion of Silicon into Steel. H. Cornelius. (Metallwirtschaft, 1938, vol. 17, Mar. 11, pp. 273–276). The diffusion of silicon into carbon steel at temperatures above 900° C. results in the formation of a ferritic diffusion zone containing considerable amounts of silicon. If the specimen is not of too small a section this zone is devoid of free or combined carbon. The diffusion of the carbon into the interior of the test-piece is discussed. The γ-iron-carbon solid solution takes up only small quantities of silicon by diffusion. Since in the outer zones of the test-piece the carbon content is reduced to a minimum and since the austenitic core takes up little silicon, test-pieces of moderate section show no graphitisation even after cementing in silicon at 900–1100° C. for as long as 50 hr., although with specimens 1·5 mm. in dia., treated for this period at 1100° C., a little graphite was observed; the mechanism of its origin is considered, both in this particular instance and in cases where the experimental conditions are such that the core of the test-piece becomes saturated with carbon and where iron carbide remains in the outer zones and eventually undergoes decomposition.

Acceleration of Case-Hardening by Means of an Electric Current. N. T. Gudtzov and I. A. Sumin. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 55–57). (In Russian). The authors compare the depth of case obtained by heating cylinders of Armco iron and of 0·18% carbon steel 15 mm. in dia. by 30 mm. in height in a mixture of 63% of charcoal, 20% of electrode scrap and 17% of barium carbonate, both with and without an electric current (2–10 amp.) passing through the compound and the specimens. The current accelerates carburisation owing, probably, to the heating effects occasioned by the high resistance of the carburising agent and to the formation of minute arcs between the surfaces of the specimens and the fragments of compound in contact with them. With a current of 4 amp. an increase in depth of case from 0·45 mm. to 0·7 mm. was observed, whilst at 10 amp. a case 1·10 mm. in thickness was formed. In all specimens a thicker case was obtained when the steel was attached to the positive pole of the supply. No cementite network was produced in any specimens; an explanation is advanced for this.

New Dry Cyaniding Process Developed by Surface Combustion Engineers. (Iron Age, 1938, vol. 141, Mar. 3, pp. 58–59).

Dry Cyaniding. (Steel, 1938, vol. 102, Feb. 21, pp. 62–64). Carburising is carried out in a mixture of carburising gases and ammonia in a process known as "dry cyaniding" developed by the

Surface Combustion Co., Toledo, Ohio. A case with any desired concentration of carbides and nitrides and ranging in thickness from a few thousandths of an inch upwards is said to be readily produced. Some details are given respecting suitable heat treatments for the case.

Atmospheric Control, Electric and Salt Baths. (Wire Industry, 1938, vol. 5, Feb., pp. 83–85). An account is given of the production of controlled atmospheres by the use of producer gas (the drawbacks of which are discussed) and of partially-burnt town's gas. The advantages of the electric furnace for annealing purposes are dealt with, some details being given of the construction of types suitable for treating wire. The use of the salt bath is also considered and its advantages as compared with coal or gas-fired muffle-type furnaces are noted.

Selective Hardening with the Oxy-Acetylene Flame. R. L. Rolf. (International Acetylene Association: Welding Journal, 1938, vol. 17, Feb., pp. 6–9).

Selective Hardening of Ferrous Metals with the Oxy-Acetylene Flame. R. L. Rolf. (Iron Age, 1938, vol. 141, Feb. 17, pp. 32–35, 52). (*See* p. 192 A).

Flame Hardening. J. T. Howat. (International Acetylene Association, Nov., 1937: Canadian Metals and Metallurgical Industries, 1938, vol. 1, Jan., pp. 32–33: Welding Journal, 1938, vol. 17, Feb., pp. 23–25: Steel, 1938, vol. 102, Feb. 28, pp. 60–63). The author briefly describes the development of the flame-hardening process, considers the mechanical and metallographic characteristics of a flame-hardened surface, summarises the technique employed and notes a few of the more usual applications.

Application of Flames for Localised Metallurgical Treatments: Heating, Tempering and Hardening, Forging and Carburising. A. Leroy and J. Fassbinder. (VIII^{e} Séance d'Études Thermiques, Dec. 16, 1937: Chaleur et Industrie, 1938, vol. 19, Jan., pp. 163–166). The authors briefly summarise the purposes of localised heating, discuss the general characteristics of temperature localisation in a metallic body and describe sources of heat suitable for localised heating together with the fields of application of each source. The various flames used for localised heating are compared mainly from the standpoint of thermal efficiency.

Influence of Catalysts on the Nitrogen-Hardening of Steels. I. F. Afonskii. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 8–14). (In Russian). The author discusses the results of experiments on the absorption of nitrogen (from cracked ammonia) at 500° C. by a steel containing 0·75% of carbon, 1·16% of silicon, 0·77% of manganese, 2·22% of chromium and 0·8% of aluminium, in the presence of magnesite as a catalyst. The thickness of the nitrided zone was not increased but the time required to obtain a layer 0·3 mm. thick was reduced from 18 to 8 hr. It is important to note that the catalyst must not prevent access of the gas to the

steel such as occurs if the sample is packed in magnesite. The author suggests covering the inner wall of the furnace with a magnesite/silicate mixture which will protect the furnace and at the same time accelerate the hardening process—probably by influencing the dissociation equilibrium of the ammonia. Magnesium oxide has a similar action to that of magnesium carbonate.

Physico-Chemical Bases of the Decarburising and Scaling Processes Occurring with Iron and Steel. C. Wagner. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Mar., pp. 449–454). The decarburisation of steel by carbon-dioxide/carbon-monoxide mixtures depends on the sum of the partial pressures of the two gases, the ratio of the partial pressures and on the temperature. Assuming that the diffusion of carbon in the iron constitutes the most protracted part of the decarburisation process, formulæ are derived to express the progress of the reaction as a function of time. The case of very thin sheet steel is specially considered. Diffusion processes through the solid oxide layer, if very slow, are shown to obey the law of Tammann, but other factors may interfere and prevent the strict application of this law; these factors are discussed.

Heat Treatment of Steering Gear Parts. R. Flury. (Industrial Heating, 1938, vol. 5, Feb., pp. 131–138, 160). The author describes the heat-treatment department of the Gemmer Manufacturing Company (U.S.A.), producers of automobile steering gear. Both equipment and procedure are considered in detail together with the nature of the components produced. The plant includes Ajax-Hultgren electrically-heated hardening furnaces (in which a salt bath is heated, by resistance, by the passage through it of an alternating current), drying ovens operating at 250–270° F. on exhaust gases from the hot-water rinsing tanks, sodium-nitrate baths heated by high-pressure butane gas, and an annealing furnace operating at 300–400° F. on circulated, heated air. The furnaces described are incorporated into two production lines.

Coil Spring Manufacture at Chevrolet. J. B. Nealey. (Heat Treating and Forging, 1938, vol. 24, Feb., pp. 61–64). The author describes the manufacture of coil springs at the Chevrolet Forge Spring and Bumper Division of the General Motors Corporation, Detroit. Special attention is paid to the heat-treating equipment, which consists of gas-fired continuous furnaces for annealing, hardening and tempering. Structural and operating data regarding the furnaces are presented.

Spring Wire and Springs. R. Saxton. (Wire Industry, 1938, vol. 5, Feb., pp. 67–68). For the production of helical springs the two most commonly used steels are Bessemer quality with carbon up to about 0·22% and the so-called hard-drawn wire containing 0·50–0·65% of carbon, 0·70–1·00% of manganese and 0·08–0·25% of silicon. The heat treatment of each of these grades is described together with the procedure for coppering by the wet method (the initially loosely-adhering copper deposit acts as a lubricant during

the final drawing operation and at the same time is bonded firmly to the basis metal), and galvanising by the hot-dipping and electro-depositing processes. In conclusion spring-forming operations are dealt with.

Modern Heat Treating of Boiler Tubes. J. M. Brown. (Iron Age, 1938, vol. 141, Mar. 3, pp. 50–51). An account is given of the surface-combustion continuous furnace at the Cleveland plant of Steel and Tubes, Inc., for normalising, annealing and blueing boiler tubes. The process of manufacture of the tubes is outlined and the operation of the furnaces and the heat treatment cycle are dealt with. Radiant-tube heating is employed, the atmosphere in the heating and cooling zones being " DX gas " (cracked natural fuel gas).

Comparative Effects of Controlled Atmospheres on Alloy and Carbon Steels. E. E. Slowter and B. W. Gonsor. (Metals and Alloys, 1938, vol. 9, Feb., pp. 33–39; Mar., pp. 59–62). Carbon dioxide and water vapour are equally detrimental to medium- and high-carbon alloy steels and to medium- and high-carbon non-alloy steels, hence they should be removed from an atmosphere designed to protect work during heat treatment. If partly burnt gases are not entirely dried their action on carbon and alloy steel at temperatures above 1600° F. is as severe as that of the completely undried gases; at lower temperatures it is somewhat less severe. With few exceptions any atmosphere suitable for a given range of carbon steels is also suitable for a similar range of alloy steels of equal carbon contents, which, while behaving similarly to the former type of steels, are slightly more resistant to attack, particularly at lower temperatures. Steels containing relatively high silicon contents are more resistant to carburisation and decarburisation than plain carbon steels of equal carbon content. High- and low-chromium steels are very susceptible to oxygen-containing gases; carbon monoxide will be reduced under certain conditions in the presence of these steels. Nickel steels are more resistant and low-chromium steels less resistant to fogging during heat treatment than plain carbon steels.

Progress in Convection Furnaces. (Industrial Heating, 1938, vol. 5, Feb., pp. 114–130). An account is given of convection-type furnaces, some indication being made as to the general field of utility of different types. Vertical and horizontal batch-type furnaces and continuous-conveyor-type convection furnaces are dealt with; constructional and operating data are presented.

Strip Annealing. T. N. Keelan. (Steel, 1938, vol. 102, Jan. 24, pp. 56–59). The author analyses and compares the annealing practices in use at various plants producing hot- and cold-rolled strip and discusses the principal chemical, physical and mechanical factors controlling the details and course of the process as applied to different grades of strip. The features incorporated in good annealing practice are summarised. The advantages and disadvantages of slow and rapid heating are briefly dealt with.

Annealing Cold Strip. T. N. Keelan. (Steel, 1938, vol. 102, Feb. 14, pp. 40–44). The author presents an analysis of the heat-treatment practices for cold-rolled steel strip at various mills. Data are presented in tabular form for box-type and radiant-tube furnaces and for various gauges and widths of strip (up to 90 in.). Details are also given respecting the production of three types of surface finish—black, steam blue and deoxidised; the last finish is considered at some length and the cause and prevention of certain common defects are dealt with.

Scale-Free Hardening Bolts Continuously. W. F. Ross. (Wire and Wire Products, 1938, vol. 13, Feb., pp. 75–78). An account is given of the continuous chain-belt conveyor-type electric furnace equipment installed by the National Screw and Manufacturing Co., Cleveland, Ohio, for heat-treating bolts. The construction of the furnace is described with special reference to the location of the heating elements. The furnace is also of the controlled atmosphere type, and is supplied with partly burnt natural or manufactured gas produced in an Elfurno gas generator forming part of the installation. Data are furnished regarding power consumption.

Oil-Fired Continuous Reheating Furnace. (Engineering, 1938, vol. 145, Mar. 18, pp. 312–313). An account is given of a small oil-fired continuous furnace for the heat treatment of cast-steel cylinders used in connection with railway draw-gear equipment. The furnace is of the pusher type, the cylinders being arranged on skids in three rows and moved forward by a compressed-air-operated mechanism. The length of the furnace is 18 ft. and the burners are arranged at the exit end. Fuel oil of specific gravity 0·95 is used and each burner is designed to consume 4–6 gal. per hr. The oil is heated to 83° C. before reaching the burners to ensure good atomisation. Operating data are presented.

WELDING AND CUTTING

(Continued from pp. 259 A–265 A)

Properties of Welding and Oxygen-Cutting Flames. R. Granjon and D. Séférian. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 153–158). The authors discuss the thermal and chemical characteristics of welding flames and their industrial and economic aspects. Similarly the flames employed for oxygen cutting are considered; the advantages and disadvantages of using various combustible gases as the heating constituent of these flames are tabulated.

Contribution to the Study of Oxy-Acetylene Blowpipes. C. Picard. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 140–144). The author discusses the theory of low- and high-pressure oxy-acetylene torches, and the influence of variations in the composition of the gas mixture on the performance of the torch. Graphical and tabular data are presented.

Loss of Adjustment in Injector-Type Oxy-Acetylene Torches. N. Manson. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 145–152). The author discusses the results of experiments undertaken to determine the cause of the sudden change in the nature of the oxy-acetylene flame consequent upon the heating of the jet of the torch during use. The apparatus employed for the experiments is described and the mechanism of the loss of adjustment of the flame considered from a physical standpoint.

Important Uses of the Oxy-Acetylene Process in Steel Mill Operations. W. J. Sannemann. (International Acetylene Association : Welding Journal, 1938, vol. 17, Feb., pp. 20–22). The author outlines the use of oxy-acetylene cutting and welding processes in blast-furnace maintenance (for example, cutting holes in " salamanders "), in the open-hearth furnace shop (opening of the tap-hole and general repair work), in rolling mills for cutting plate too heavy to be sheared, and for repairing and fabricating equipment by welding or hard-facing.

The Supplying of Blowpipes with Oxygen and Acetylene at Pressures of the Same Order. R. Magloire. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19, Jan., pp. 197–198). The author discusses the advantages of employing oxygen and acetylene at approximately similar pressures in welding torches and the realisation of these advantages in practice.

The Atomic-Hydrogen Flame. Investigation of the Dissociation of the Gas in the Arc. D. Séférian. (VIIIe Séance d'Études Thermiques, Dec. 16, 1937 : Chaleur et Industrie, 1938, vol. 19,

Jan., pp. 76–83). The author discusses the theory of the atomic-hydrogen flame, considers the thermodynamics of the dissociation of the hydrogen molecule and the conductivity of molecular hydrogen and examines the temperature of the atomic-hydrogen flame (calculated true value = 4000° K.). In conclusion some investigations on the dissociation of gases in the Langmuir arc are di cussed; nitrogen, ammonia, and helium-nitrogen mixtures are referred to.

New Aids for Arc, Gas and Spot Welding. F. J. Oliver. (Iron Age, 1938, vol. 141, Feb. 17, pp. 47–51). Brief descriptions are given of improved types of bending rolls for rolled sheet and sections, welding generator sets, electrode holders, a rapid preheater for use on alloy steel pipes prior to welding, torch cutting machines, safety hose for gas-welding equipment, spot-welding plant and acetylene generators.

British Standard Specification for Electrodes for Metal Arc Welding in the Construction of Ships. (British Standards Institution, No. 782–1938). Electrodes for metal arc welding in the construction of ships shall be suitable for welding mild steel having a tensile strength of 26–32 tons per sq. in. and shall comply in every respect with other requirements set out in the specification.

Electric Resistance Welding in the Workshop. R. Salelles. (Revue de la Soudure Autogène, 1938, vol. 30, Feb., pp. 329–330). A brief description is given of the possibilities of employing resistance welding for the fabrication of light components in ferrous and non-ferrous metals. The rapidity with which operatives can become familiar with resistance welding technique is stressed.

Economy in Materials by Means of Resistance Welding. W. Fahrenbach. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Feb. 26, pp. 241–244). Various applications of electric resistance welding of various types are described. Possible uses consist either of assembling various units of a structure by welding or of joining up small semi-finished items such as pieces of sheet or rod into larger masses for subsequent utilisation. In particular the jointing of dissimilar materials, such as the shank of a drill to the working part of the tool, by welding is noted, such a process enabling considerable economies to be effected in expensive alloy steels.

Why Not Weld Electrically? (Philips Industrial (Philips Lamps, Ltd.), London). A small handbook giving a general outline of the principles of electric welding. The technique of different methods of electric welding is discussed together with details of welding plant, welding rods of different types and the mechanical testing of welded joints.

Bicycle Tubing Welded by the Hart Process. (Iron Age, 1938, vol. 141, Feb. 10, pp. 48–51). An account is given of the jointing of steel bicycle tubing by the Hart process (U.S. Patent 2,091,982), which is an electrical resistance method involving three stages: Reinforcement of the tube ends; backing off the edges to be welded

to form a thin V groove; welding under heavy pressure for a short period with high current densities. The reinforcement consists of a short length of knurled 14-gauge tubing which is driven into the tube to be joined to form an internal collar. The welding cycle is controlled by an electron tube.

Different Welding Processes and Difficulties Encountered in the Welding of Stainless Steels. A. Boutté. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Nov.–Dec., pp. 2906–2912). The author discusses the technique of welding the ferritic and martensitic chromium steels by the oxy-acetylene and electric-arc processes. In connection with the welding of the austenitic stainless steels the oxy-acetylene, arc and resistance methods are discussed together with the atomic-hydrogen process; soft soldering and brazing are also briefly referred to.

The Applications of the Welding of Stainless Steels in Sheet Metal Works and the Tin Smithy. A. Bignier. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Nov.–Dec., pp. 2913–2919). The author describes the fabrication by welding of vessels, tubular structures and hoods in 18/8 stainless-steel sheet. The mechanical working of the sheet, pickling operations and the use of steel sheet clad with stainless steel are also dealt with.

Utilisation of 18/8 Stainless Steel and its Assembly by Resistance Welding in the Construction of Rolling Stock. C. Loiseau. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Nov.–Dec., pp. 2920–2936). The author refers in his introductory remarks to the difficulties of mechanically working 18/8 stainless steel especially with regard to such operations as drilling and cutting of sheet. Welding is recommended as the most reliable and economic method of assembling sheet structures. Welding equipment for the resistance welding of stainless steel sheet for rolling-stock construction is dealt with at length.

Welding Cracks in Chromium-Molybdenum Steels. P. Bardenheuer and W. Bottenberg. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 375–383). The influence of melting procedure upon the weld-sensitivity of chromium-molybdenum steels was investigated upon a number of experimental melts. The Focke-Wulf testing method was used, the plates being 1 mm. in thickness. Whilst the weld-sensitivity of the material increased with increasing amounts of carbon, aluminium, phosphorus, and especially sulphur, at the same time the influence of the steel-refining technique was far greater than that of any of these factors. Low sensitivity depends on a prolonged and strong boiling of the charge; no effect of melting or pouring temperature could be determined. Cold-working also had no influence on weld-sensitivity. Cracking occurs in the neighbourhood of the transformation temperature; from this it was concluded that structural stresses consequent upon the pearlitic and martensitic changes, together with mechanical and thermal stresses, contribute to the formation of cracks.

Differences observed in the behaviour of the various materials result from the effects of hydrogen; when this gas is absorbed during welding it only leads to stresses when the material being welded contains a certain amount of non-metallic inclusions. The oxide content should be maintained at as low a level as possible by careful melting practice. The lower the oxide content the higher are the permissible phosphorus and sulphur contents which cannot always be controlled by melting practice. The larger the grain size the more readily does hydrogen tend to cause cracking. The hardness of the weld depends mainly on the composition of the steel and bears no direct relationship to the tendency to crack on welding.

MACHINING

(Continued from p. 266 A)

Grinding in the Foundry. A Duplex High-Speed Machine. (Iron and Steel Industry, 1938, vol. 11, Feb., pp. 194–195). A high-speed grinding machine of the two-wheel type is fitted with independent speed-change equipment to each wheel, thus enabling both wheels to be run at optimum peripheral speeds irrespective of different diameters due to varying degrees of wear.

Roll-Grinding Machines. R. Whibley. (Sheet Metal Industries, 1938, vol. 12, Feb., pp. 177–179, 180). The author discusses briefly the essential features of a roll-grinding machine and in particular deals with the various types of cambering mechanism; each of these is considered in detail both from the standpoint of construction and from the point of view of accuracy of the surface produced. Moving wheelhead and moving work-table types are compared. In conclusion the finish obtained by roll grinding is discussed.

Machine Tools for Cutting and Grinding. H. Opitz. (Zeitschrift des Vereines deutscher Ingenieure, 1938, vol. 82, Feb. 26, pp. 218–231). The author reviews salient features and the more recently developed designs of lathes (automatic and semi-automatic types), milling machines, drilling machines (single and multi-spindle types), fine-boring machines, precision surface grinders, gear-cutters and grinders, of German origin. Special attention is paid to the driving, controlling and regulating mechanisms.

The Cutting Capacity of High-Speed Steels of Different Compositions and of Hard-Metal. F. Rapatz, H. Pollack, and J. Holzberger. (Stahl und Eisen, 1938, vol. 58, Mar. 10, pp. 265–275). Comparison of the cutting capacities of normal high-speed steels under conditions as to cutting speed which give a useful life to the tool of 60 min. and under those conditions obtaining in normal industrial practice shows that the V_{60} values (*i.e.*, the cutting speeds at which the useful life of the tools is 60 min.) of the most highly alloyed and least alloyed steels are in the ratio of about 1·75 : 1; the useful lives of the tools under normal operating conditions stand in much more marked contrast. These observations apply both to low- and to high-tungsten steels. If sufficient vanadium is present, the need for a high tungsten content in order to attain high cutting capacity becomes much less; steels with 10–13% of tungsten and increased contents of molybdenum and vanadium are quite equivalent in cutting capacity to 18% tungsten steel, although their hot-hardness is somewhat less and they are sensitive to overheating. Vanadium above 3% confers no increase in cutting capacity. Whilst they are somewhat difficult to manipulate, the molybdenum steels are to be recommended. The tendency of the lower-alloy

steels to crack is explained by their stronger tendency to grain growth, which, in turn, is due to their lower carbide content and to their higher hardness on quenching owing to the smaller proportion of residual austenite. The cutting capacity of sintered hard-metals is, according to the exact nature of the operation upon which they are engaged, three to ten times that of high-speed steels and 1·5–3 times that of alloys of the stellite type. The marked difference between titanium-bearing and titanium-free hard-metals in cutting grey cast iron and steel is to be attributed to the different chip form produced and to the differing thermal conductivities of each type. In so far as turning operations are concerned, hard-metals find practically universal application in Germany, but for other operations it appears that the use of these materials has practically reached its maximum extent.

Drilling Tests on Unalloyed Steels. H. Opitz and H. Jansen. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 385–391). Drilling tests on unalloyed steels of various compositions and heat-treated variously demonstrated that whilst the carbon content and the microstructure influence the amenability of the material to drilling, the Brinell hardness is of greater significance in this respect with regard to the members of any particular group of steels. The dependence of the ability of the material to be drilled upon its hardness is a particularly useful property for practical purposes in estimating the most economic cutting speeds for various materials. A table is presented of V_{L2000} values—values for the cutting speed at which the drill is blunted after boring a hole 2000 mm. deep—for different feeds, drill diameters and materials of different Brinell hardness numbers. The experimental procedure adopted and the equipment used for deriving the above data are described. The determination of the amenability of a material to drilling and the fixing of optimum drilling speeds may be carried out by a series of drilling tests in which holes are drilled one after the other at a constantly increasing drilling speed until the efficiency of the drill begins to drop; the method of deriving V_{L2000} from the data so obtained is described.

PROPERTIES AND TESTS

(Continued from pp. 272 A–288 A)

Yield Point of Single Crystals of Iron Under Static Loads. M. Gensamer and R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, Technical Publication, No. 893 : Metals Technology, 1938, vol. 5, Feb., No. 2). Static tensile tests on nine single crystals of decarburised mild steel, in which elongation was measured with a sensitivity of 10^{-5} in. per in., have shown the existence of a true yield point, a stress below which no permanent elongation occurs. At stresses at which yielding occurs the rate of elongation is initially low, then increases, and finally decreases to zero.

The Yield Point in Metals. M. Gensamer. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 894 : Metals Technology, 1938, vol. 5, Feb., No. 2). Discussing the yield point in metals the author develops the following points. A transition between homogeneous and heterogeneous flow will occur at every point on a flow curve (true stress-strain curve) when the slope equals the true stress. Whether or not the yield point will be characterised by heterogeneous flow (Lüders' lines; the Piobert effect) is determined by the stress at the yield point and the rate of work-hardening of the material. Increasing the speed of the test raises the yield point stress and lowers the rate of work-hardening of the material. The theory that work-hardening is caused by the development of internal stresses provides a simple explanation for elastic recovery.

Yield Point in Mild Steel. Consideration of the Higher and Lower Values. G. Cook. (Institution of Engineers and Shipbuilders in Scotland, Feb. 22, 1938 : Iron and Coal Trades Review, 1938, vol. 136, Feb. 25, pp. 353–354, 358). The author refers to the controversy regarding the respective merits of the higher and lower values for the yield point to be claimed as the true yield point, and discusses the effect of rate of increase of strain on the yield point values, yield point in compression, and the effects of shape and surface condition. The lower value shows a greater constancy under a variety of loading conditions than the upper value. The upper value appears also to be more susceptible than the lower to conditions not inherent in the material itself.

Effect of Thickness of Flat Test-Pieces on the Results of the Tensile Test. S. A. Kushakevich. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 86—92). (In Russian). The author describes the results of an investigation of the effect of specimen thickness on the tensile strength of flat test-pieces cut from sheets 0·25–2 mm. in thickness and cold-worked to varying degrees. The

tensile strength was found to increase with decreasing cross-section in cold-worked specimens, whilst with changes in thickness variations of 8–15% were observed in the tensile strength.

On the Graphical Interpretation of the Results of the Jovignot Test. P. Tongas. (Revue de Métallurgie, Mémoires, 1937, vol. 34, Dec., pp. 702–703). The author discusses the mathematical interpretation of the results of the Jovignot cupping test.

The Influence of Repeated Cold-Working on the Properties of Chromium-Molybdenum and Nickel-Chromium-Molybdenum Steels Characterised by High Strength in the Heated State. E. Greulich and H. Zschokke. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 401–404). Experiments carried out on steels containing 0·5% of carbon, 1·3% of chromium and 0·6% of molybdenum, and 0·15% of carbon, 1·5% of nickel, 0·75% of chromium and 0·8% of molybdenum, showed that repeated cold-working with intermediate annealing increased the range in which softening by annealing occurred and decreased the maximum possible strength of the steels. This is occasioned by the increased ease of formation of banded pearlite associated with granular cementite. In the soft state produced by repeated cold-drawing and annealing the endurance strength is considerably lower than that in the hot-rolled and heat-treated state, but may be largely restored by subsequent heat treatment. With the steels tested higher endurance strengths were obtained by quenching than by annealing, for temperatures up to 500–550° C., but at temperatures over 550° C. the endurance strength obtained was about the same for either treatment; the method of producing the steel had no influence on the results obtained.

The Deformation and Fracture of Metals. H. J. Gough and W. A. Wood. (Journal of the Institution of Civil Engineers, 1938, No. 5, Mar., pp. 249–284). The authors discuss the nature of the problems encountered in investigating the deformation and fracture of metals, review previous work on the subject, consider some of the effects of deformation on the X-ray diffraction spectra of metals and deal at length with the deformation and fracture of a mild steel as observed by X-ray diffraction.

The Influence of the Degree of Forging and of Heat Treatment on the Alternating Bend Strength of Various Alloy Structural Steels. M. Schmidt. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 393–400). The alternating bend strength of heat-treated steel containing 0·27% of carbon, 0·85% of chromium, 3·18% of nickel and 0·32% of molybdenum was determined on specimens forged from an ingot to sections 5/22–1/22 that of the original section of the ingot; values were determined both parallel and at right angles to the direction of forging. Whilst the tensile strength and impact values varied considerably between specimens taken in either direction, the corresponding difference in alternating bend strength was only 15% at the most for ground and 13·5% for notched test-pieces. A further series of tests on the static tensile

properties and the impact strength and alternating bend strength of test-pieces of structural steels of different compositions with polished and notched surfaces which had been heat-treated to give various tensile strengths, indicated that notch sensitivity in general decreases with decreasing tensile strength in the case of specimens subjected to repeated stress; with medium tempering temperatures, however, notch sensitivity attains a maximum value. No definite relationship could be determined between notch sensitivity and microstructure. The ratio of alternating bend strength to tensile strength was improved by tempering at above 500° C.; the former value could be derived with moderate accuracy from the latter by means of W. Herold's formula, and whilst the expression suggested by Lequis, Buchholtz and Schulz for calculating the alternating bend strength from the yield point, tensile strength and elongation yields somewhat high values, it is, nevertheless, possible to employ it quite satisfactorily.

Investigation of Abrasion and Fatigue of Steel Axles. L. I. Kukanov. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 51–60). (In Russian). The author discusses the results of an investigation of the wear and fatigue of railway-carriage axles; the effects of the diffusion of bronze from the bearings into the journals are examined. Wear resistance increases with increasing manganese contents from 0·7% to 1·1–1·27% (the carbon content of the steels being 0·30–0·35%). Repeated heating from 20° to 350° C. decreases the fatigue limit by 19%, while the diffusion of bronze into the journal at 900–1000° C. decreases the impact value by 20–28%, although the fatigue limit at room temperature remains unchanged.

Magnetic Investigations on the Precipitation-Hardening Iron-Nickel-Tin Alloys. H. Legat. (Metallwirtschaft, 1938, vol. 17, Mar. 11, pp. 277–278). Remanence and coercive-force phenomena were investigated on low-carbon iron-nickel-tin alloys containing 0–25% of nickel and 0–24% of tin. The alloys were tested in the hardened condition. It was determined that the separation of the tin-rich phase alone did not condition higher magnetic-hardness values. At about 10% of tin and above the nickel content required to produce austenitic nickel-iron alloys a decrease in coercive force was observed. As a principal alloying addition to permanent magnet steels tin finds no application, but as a minor alloying constituent is of considerable value.

Symposium on Wear of Metals. (American Society for Testing Materials, 1937). Among the papers presented on Apr. 5, 1937, in Philadelphia at a symposium on the wear of metals sponsored by the Philadelphia District Committee of the American Society for Testing Materials, were the following: Considerations involved in the Wear Testing of Metals, by H. W. Gillett; Some Important Variables Encountered in Wear Tests on Cast Iron, by D. E. Ackerman; Wear of Metals from the Automotive Standpoint, by W. E. Jominy; Wear from the Power Equipment Standpoint, by N. L.

Mochel; Wear of Metals in the Textile Industry, by A. Palmer; Wear of Metals from the Railroad Standpoint, by L. W. Wallace.

Comparison of the Tensile Deformation Characteristics of Alloys at Elevated Temperatures. C. R. Austin and H. D. Nickol. (Iron and Steel Institute, May, 1938; this Journal, p. 177 P). In Part I. of the paper, details are presented of a new type of equipment for the comparative study of stress/deformation/time relationships of alloys at elevated temperatures. The behaviour of seventeen alloys at 600°, 700°, and 800° C. under stresses ranging from 2000 to 8000 lb. per sq. in. is indicated by tabulated data and by deformation-time curves arranged to illustrate the three classes of alloys studied:

(1) Austenitic stainless 18/8 steels.
(2) Ferritic chromium-iron alloys.
(3) Konel-type alloys—*K42B* and modifications.

A few data are also included relating to resistance to deformation at 1000° C., and at 950° C. in a hydrogen atmosphere.

Consideration has been devoted to the reproductibility of the test data, to negative dilatation of the alloys, to a comparison of results from single and multiple loading, and finally to the distribution of the data from tests exhibiting low and high rates of deformation.

Part II. provides a metallographic study of the effect of temperature and stress on stainless 18/8 steels, chromium irons, and konel-type alloys. Details of the preparation of the samples and of the etching technique are described.

A comparison of the general structural features of the alloys includes the observation that stress plays an important rôle in the rate of precipitation and aggregation of a disperse phase, and hence in the high-temperature strength of alloys. There appears to be definite evidence that in chromium-iron alloys the rate of spheroidisation of the small amount of carbide present is markedly greater at the higher stresses.

An increase in the susceptibility to magnetism correlates with the decrease in strength and the increase in brittleness of the stainless 18/8 alloys.

In a general discussion of the investigation, diagrammatic pictures are presented to show (1) the marked relative superiority of austenitic stainless steels over ferritic chromium irons in their resistance to deformation at elevated temperatures, and (2) the comparative deformation rates of the three classes of alloys and their general distribution with respect to creep rate, stress and temperature.

The Effect of Copper on Some Alloy Steels. R. Harrison. (Iron and Steel Institute, May, 1938; this Journal, p. 285 P). The mechanical properties of a number of alloy steels containing from 1 to 6% of copper, in the oil-hardened and tempered and in the temper-hardened conditions, have been examined. The maximum increase

in hardness due to temper-hardening was obtained in a low-carbon steel containing 0·5% of chromium and 1·6% of copper. Increasing the alloy content in order to obtain a higher final hardness introduced a tendency to air-hardening, and the temper-hardening effect was gradually masked by the softening due to normal tempering. The highest tensile strength obtained by temper-hardening alone—that is, in the absence of any air-hardening during normalising—was just over 50 tons per sq. in. The low Izod impact figures usually associated with the temper-hardening process were considerably improved by increasing the reheating time or temperature.

Although temper-hardening may provide material of good properties when the composition and treatment are carefully chosen and may prove useful in particular cases, it is not likely to displace the usual method of oil-hardening and tempering for ordinary materials of construction.

Copper may, however, prove to be a useful alloy element in steels to be used in the hardened and tempered condition. Considerably higher tensile properties were obtained in a medium-carbon steel containing 1·0% of copper than in a similar steel containing 1·4% of nickel, and the properties of a 3·4% copper, 0·9% chromium steel were slightly better than those of a 3·5% nickel, 0·9% chromium steel.

If difficulties in mechanical treatment result from the limitation of the forging temperature necessitated by high copper contents, a steel containing nickel and copper, free from these limitations, may be employed without detriment to the mechanical properties.

The Effect of Chromium and Carbon Contents on the Coefficients of Thermal Expansion of Chromium Steels. J. A. Jones and W. C. Heselwood. (Iron and Steel Institute, May, 1938; this Journal, p. 361 P). The construction of a sensitive dilatometer for the accurate determination of coefficients of thermal expansion up to 1000° C. is described, and results are presented of measurements of the coefficients of expansion of two series of chromium steels, (*a*) low-carbon steels containing up to 32% of chromium, and (*b*) medium-carbon steels containing up to 19% of chromium.

With increasing chromium content, the low-carbon series shows a continuous decrease in the expansion coefficients. In medium-carbon steels, however, the effect of chromium additions up to approximately 4¼ times the carbon content is to increase the values of the expansion coefficients, especially at the lower temperatures; further additions of chromium have the effect of lowering the values, the general form of the curves becoming similar to those obtained for the lower-carbon steels. This phenomenon appears to be associated with the ratio of the chromium to the iron in the carbides present in the steels.

Report of the Grey Cast Iron Congress of the Verein deutscher Giessereifachleute, Leipzig, 1938. (Giesserei, 1938, vol. 25, Feb. 11,

pp. 49–55). Summaries are presented of a number of papers read before the Grey Iron Congress of the Verein deutscher Giessereifachleute, held in Leipzig, Jan. 28–29, 1938. Among the papers dealt with are the following: Light Structural Components in Cast Iron, by A. Thum; Recent Knowledge concerning the Structural Strength of Cast Iron, by E. Mickel; The Behaviour of Cast Iron Exposed to Chemical and Thermal Influences, by F. Roll; The Wear Resistance of Cast Iron, by Freiherr von Schwartz; Welding or Casting? by C. Stieler; Melting, Structure and Mechanical Properties of Grey Cast Iron, by P. Bardenheuer; Centrifugally Cast Liners, by W. A. Geisler; Concerning the Melting of Grey Cast Iron in the Electric Furnace, by O. Glaser.

The Influence of Copper on Malleable Cast Iron. F. Roll. (Giesserei, 1938, vol. 25, Feb. 25, pp. 80–84). The author discusses the effect of copper additions on the tendency of cast irons to assume the white or grey forms in sections of different thicknesses, considers the solubility of copper in alloys of iron and deals at length with the influence of copper on the mechanical and corrosion-resistance properties of whiteheart and blackheart malleable cast iron; the experimental procedure adopted in investigating these last properties is briefly outlined. The effect of copper on the casting characteristics of the irons is also discussed.

New Cast Irons Heat Treated and Rolled. D. P. Forbes. (Metal Progress, 1938, vol. 33, Feb., pp. 137–142). The author refers to the production of non-alloy grey cast irons with tensile strengths up to 31·2 tons per sq. in. Certain factors controlling high tensile values are considered and it is noted that high-strength cast irons are naturally difficult to machine owing to the structure of the matrix which resembles that of a heat-treated high-carbon steel and may have a hardness value up to 300 Brinell. The tensile strength and hardness of grey cast iron can be increased by quenching in oil from about 871° C. and tempering at 427° C. With silicon above 2% this operation becomes difficult, but is extremely beneficial with irons containing less than 3·0% of (total) carbon. A detailed account is given of the heat-treatment practice for cast iron and of difficulties encountered in connection with oxidation, decarburisation and growth. Special malleable cast irons are also dealt with. The manufacture of pearlitic malleable is outlined and its structure and mechanical properties are briefly dealt with; its tensile strength varies from 24·5 to 53·5 tons per sq. in. The production of rolled white iron is also described and its structure and properties are briefly dealt with.

Comparison between Forged Steel and Centrifugally-Cast Iron Pipe Lines. S. Cantacuzène. (Génie Civil, 1938, vol. 112, Mar. 12, pp. 225–227). The author compares the mechanical, physical and corrosion-resistance properties of seamless steel and centrifugally-cast iron conduit for water and petrol. Particular attention is paid to the permissible methods of jointing each type of tube, and

the limitations which are introduced as a result into the fields of application of cast iron are noted.

Cast-Iron Crankshafts. T. Klingenstein, H. Kopp and E. Mickel. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1938, vol. 6, Feb., pp. 39–51). The authors emphasise the strongly adverse effects of the notch effect and general shape of a crankshaft upon the relationship between the actual strength of forged steel and the strength of a forged steel crankshaft, which may amount to only a few per cent. of the true value for the material. Attempts to increase the strength of such a crankshaft by structural modifications result in unreasonably heavy expenditure of money, time and labour. The specially low notch sensitivity and high damping capacity of cast iron enable crankshafts to be produced by casting which are no less durable than steel, if a suitable iron and design are employed for the purpose; in particular, where vibration in the crankshaft is likely to occur then cast iron is definitely recommended since its damping capacity will constitute a considerable proportion of the total damping capacity of the engine. "Essling" crankshaft iron (composition not stated) prepared by the duplex process in the cupola and electric furnace possesses all the required properties; it is a low-alloy cast iron with a pearlitic matrix, needs no hardening or other heat treatment and is relatively cheaper than steel.

Investigation of the Open-Hearth Process in Relation to the Faults due to Non-Metallic Inclusions found in Rolled Plates for Electric-Locomotive Frames. M. A. Galperin. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 21–30). (In Russian). The author examined the mechanical properties of test-pieces from faulty locomotive frames and compared these properties with the composition of the steel and the number of non-metallic inclusions in it; no direct relationship could be traced. Melting practice and methods of reducing the number of inclusions are also discussed.

Influence of Sulphide Inclusions on the Structure and Mechanical Properties of Steel. S. M. Skopodzievskii. (Metallurgist, Russia, 1937, vol. 12, No. 3, Mar., pp. 15–21). (In Russian). Steels containing from 0·5 to 0·91% of manganese and 0·12–0·16% of carbon produced in a small converter tended to give low elongation values. In experimental melts a considerable number of inclusions were found, consisting, in the case of the higher manganese contents and in the presence of greater concentrations of sulphur, mainly of manganese sulphide segregated at the boundaries of the ferrite dendrites. Increasing numbers of inclusions resulted in a more pronounced dendritic formation and an increase in grain size which could not be reduced by normalising. The brittle sulphide inclusions prevented flow and hence diminished elongation, the effect depending on the number rather than the size of the inclusions. Increasing casting temperatures favoured the formation of dendritic structures and the occurrence of sulphide inclusions.

Ludlite. Stainless for the Hoi Polloi. T. W. Lippert. (Iron Age, 1938, vol. 141, Feb. 17, pp. 24–31).

A New Form of Stainless Steel. (Steel, 1938, vol. 102, Feb. 21, pp. 46–48). A material manufactured by the Ludlum Steel Co., Watervliet, New York, and marketed under the name of " Ludlite " is described. It consists of a very light gauge silchrome stainless steel bonded by heat and pressure to a flexible backing of asphalted felt. It is supplied in rolls 24 in. wide and in lengths of 50 ft. No special tools are required to cut this material and it may be applied to any surface by means of a special waterproof cement.

Heat-Resisting Steels. W. H. Hatfield. (Institute of Fuel, Mar. 24, 1938). The author presents a comprehensive study of heat-resisting steels which are considered under the following heads: Typical applications of heat-resisting steels; comparative study of resistance to oxidation or scaling; comparative study of the strength as affected by increasing temperature; the structure of the steels as affected by temperature. A summary is presented of the principal matters covered under these headings and in an appendix the detailed properties of each material dealt with are noted. Tabular and graphical data are included in the paper.

General Characteristics of the Principal Rustless and Heat-Resisting Steels. R. Colvez. (Bulletin de la Société des Ingénieurs Soudeurs, 1937, vol. 8, Nov.–Dec., pp. 2899–2905). The author discusses the part played by the chief alloy additions made to corrosion- and heat-resisting steels and afterwards deals in greater detail with the martensitic and ferritic chromium steels and the austenitic nickel-chromium steels.

Metallurgical Progress and the Steam Engineer. L. Sanderson. (Steam Engineer, 1938, vol. 7, Feb., pp. 204–205, 208). The author discusses the development of various heat- and corrosion-resisting steels with particular reference to those of value in steam-engineering practice for use in firing equipment, boilers and auxiliary equipment and turbines. Digby's " cypritic " stainless steels are mentioned and it is pointed out that they show a tendency to surface pitting and that certain doubts have been cast upon their utility on account of their abnormal structure. It is also noted, however, that the physical and mechanical properties of this class of steels are good and that they have a high impact strength. Some applications of cypritic steels are listed.

Acid Resisting Steels. C. M. Carmichael. (American Society for Metals, Oct., 1937: Canadian Metals and Metallurgical Industries, 1938, vol. 1, Jan., pp. 29–31). The author discusses the development of stainless steels, their heat treatment, types of stainless steel (the use of additions of molybdenum to 18/8 for the purpose of increasing the resistance to corrosion is specially noted), and the selection of the correct types of steel and designs for particular purposes.

Carbon-Molybdenum Steels. W. F. Chubb. (Iron and Steel Industry, 1938, vol. 11, Feb., pp. 165–168). The author presents a

review of the properties and applications of carbon-molybdenum steels from the standpoint of general engineering practice. It is concluded that molybdenum improves the machinability, particularly in regard to the surface finish which may be obtained. The most advantageous uses of carbon-molybdenum steels depend considerably upon their superior properties at elevated temperatures. The author compares the mechanical properties of carbon-molybdenum steels at elevated temperatures with those of carbon steels within the same temperature range. For boiler plate the molybdenum-bearing steel is definitely superior both with respect to mechanical properties and to weldability and the strength of welded joints. Such steels are also advantageously used for deep-drawing purposes. Carbon-molybdenum steels are considerably less susceptible to overheating during normalising and hardening than plain carbon steels. During carburising, molybdenum increases the rate of carbon penetration to a degree comparable with that of chromium. Steel castings containing molybdenum possess valuable properties both in the annealed and in the heat-treated conditions.

Steels and the Engineer. J. W. Jones. (Staffordshire Iron and Steel Institute: Iron and Steel Industry, 1938, vol. 11, Mar., pp. 253–256). The author first considers briefly the significance of the metallurgical history of a steel in relation to its mechanical properties. The value of microscopic investigation of the material and of pyrometric control during heat treatment is emphasised. Heat treatment and its beneficial effects on steel, and the origin of grain-size control together with the physical and mechanical influence of grain size in steel are next dealt with. In conclusion the relationship between grain size and machinability is discussed.

Damage to H.M.S. "Hunter." H. Stanley. (Transactions of the Institution of Engineers and Shipbuilders in Scotland, 1937). A detailed account is presented of the damage to the destroyer *Hunter* caused by striking a mine. All the important structural work, with few exceptions, was riveted; main transverse bulkheads of 6-lb. plating and over, the majority of the deep frames, and the floor plates and girders under the lower deck were welded.

Manufacture of Ordnance and Armour Plate Steels. R. D. Galloway. (Australasian Engineer, 1938, vol. 38, Jan. 7, pp. 12–15). An account is given of the manufacture, mechanical working and heat treatment of steels for armour plate. Reference is made to the use of nickel steel and nickel-chromium-molybdenum steel for the major components of guns. For chilled plate a steel of the following composition is used: Carbon 0·45–0·47%, nickel 4·0%, chromium 2·3%, manganese 0·35%, silicon 0·3%, sulphur 0·04%, phosphorus 0·04%. This steel is carburised at 980° C. Deck and roof plates are fabricated from a steel containing 0·26–0·29% of carbon, 4·0% of nickel, 1·2% of chromium, 0·24% of vanadium and 0·35% of manganese, which is used in the oil-hardened and tempered condition.

The Metallurgy of a High-Speed Locomotive. (Railway Gazette, 1938, vol. 68, Feb. 18, pp. 303–311; Feb. 25, pp. 366–370). A survey is presented of materials used in the construction of the streamlined express engines of the London, Midland and Scottish Railway. Constructional details are discussed and analytical and mechanical-test data with respect to the materials employed are elaborated in tabular form.

Steel Castings for Railways. (Railway Gazette, 1938, vol. 68, Jan. 28, pp. 184–185). A description is given of the production of steel castings for locomotives at the works of Kryn and Lahy, Ltd., Letchworth, Herts. For general castings a minimum tensile strength of 26 tons per sq. in. is required together with a minimum elongation of 20% and a cold bend test to an angle of 120°. For wearing surfaces a tensile strength of 35–40 tons is specified with an elongation of 15–10%. A special steel developed by the company and known under the name of " K. L. Stronger Steel " is referred to; it is said to possess a tensile strength of 35–40 tons and to give a minimum elongation of 20% and a cold bend test to an angle of 120°.

Nickel Steel Castings in Railroad Rolling Stock. T. N. Armstrong. (Metal Progress, 1938, vol. 33, Feb., pp. 163–166). For locomotive-frame castings a steel containing 0·2% of carbon (max.) and 2·0% of nickel (min.) is used in the double-normalised and tempered state; details of the heat treatment are given. A nickel-vanadium steel containing 0·25% of carbon (max.) and a minimum of 1·5% of nickel and 0·10% of vanadium is also used for the same purpose. For crosshead links and wheel centres a nickel-vanadium steel or a 2·0% nickel steel containing 0·25–0·35% of carbon is used, the manganese content being sometimes increased to about 1·0%. Castings for freight cars and similar uses may contain 0·30% of carbon, 1·50% of manganese, 1·40% of nickel; the advantages of this composition are discussed and the heat-treatment process to which the castings are subjected is outlined.

Service Test Results of Titanium-Treated and Silicon-Treated Steel Rails. G. W. Quick. (Journal of Research of the National Bureau of Standards, 1937, vol. 19, Nov., pp. 531–534: Iron and Steel Industry, 1938, vol. 11, Mar., pp. 245–246). (*See* p. 153 A).

Investigations of Broken Rails on Esthonian Railways. (Stahl und Eisen, 1938, vol. 58, Feb. 17, p. 171). A summary is presented of a report by P. Kandauroff which appeared originally in Monatsschrift der Internationalen Eisenbahn-Kongress-Vereinigung, 1937, vol. 8, No. 7, pp. 2111–2117. The rails described form part of the main lines of the Esthonian State Railways. They are in some cases as much as 66 years old and the incidence of fracture is becoming increasingly frequent. The results of mechanical tests, impact tests in particular, on the rails are described.

Resistance to Heat Checking of Chilled Iron Car Wheels, and Strains Developed under Long-Continued Application of Brake Shoes.

E. C. Schmidt and H. J. Schrader. (Illinois University, Engineering Experiment Station, 1937, Bulletin No. 298). The authors describe the results of an investigation upon the effects of the long-continued application of brake shoes to the treads of chilled-iron car wheels. The experimental procedure is described in detail and the results of tread endurance determinations, temperature and strain measurements and the measurement of secondary heating effects are dealt with.

Cracking Tubes in Petroleum Refineries. J. Dauvergne. (Congrès Mondial du Pétrole, 1937 : Revue de Métallurgie, Mémoires, 1937, vol. 34, Dec., pp. 676–689). The author discusses the requirements of materials for tubes employed for cracking petroleum and the behaviour of such tubes in service. The use of mild-steel tubes is considered and it is noted that this has some advantages; the service rendered by mild steel is examined at length, the effects of prolonged heating and chemical attack on the microstructure of the material being dealt with especially fully. Copper-bearing and copper-chromium mild steels, pearlitic carbon-molybdenum and chromium-molybdenum steels and chromium-molybdenum-aluminium steels are referred to in addition to stainless 18/8 cracking tubes.

Steel Castings Replace Built-up Constructions. W. M. Sheehan. (Metal Progress, 1938, vol. 33, Feb., pp. 151–156). The author discusses the use and design of under-frames for locomotives and freight cars cast in steel. Some of the essential mechanical properties desirable in steel castings for this purpose are dealt with and some reference is made to the welding of damaged frames.

Materials for Piping Systems in Automobile Construction. H. Kleyer. (Metallwirtschaft, 1938, vol. 17, Feb. 18, pp. 181–182). The author discusses the advantages to be derived from the replacement of non-ferrous (copper) tubing by steel tubing clad on the interior surface with copper. The mechanical and corrosion-resisting properties of such tubing are dealt with. The screwing and soldering of clad-tube are described and certain proprietary jointing devices are referred to.

Plastic Iron as a Packing Medium. H. Vogt. (A.B.Z., Apr. 24, 1937 : Montanistische Rundschau, 1938, vol. 30, Mar. 16, Stahlbau-Technik, p. 4). The author describes an iron-base packing compound referred to as " plastic iron " or " Eisenblei " which is intended to replace lead as a packing medium. The substance is produced by reducing, say, magnetite below the melting point of iron to produce a loose iron sponge, which is soaked in bitumen and afterwards worked up into strip stiffened with wire. The plasticity is attributed to the porosity of the metallic matrix, the microstructure of which must be carefully controlled. Some discussion is presented on the definition and determination of plasticity as required in a packing compound.

British Standard Specification for Wrought Iron Bars. " Special " Grade. (British Standards Institution, No. 762–1938). The whole

of the iron supplied under this specification shall be 100% puddled pig iron, and no scrap of any description shall be used in the puddling furnace or in the piles. Crop ends of identical iron produced in the works of the manufacturer may be incorporated up to a maximum of 10%.

British Standard Specification for Wrought Iron Chain Slings and Rings, Links Alternative to Rings, Egg Links and Intermediate Links. (British Standards Institution, No. 781–1938).

British Standard Specification for Rolled Steel Bars and Hard Drawn Steel Wire for Concrete Reinforcement. (British Standards Institution, No. 785–1938). This specification covers mild, medium-carbon or high-tensile steel manufactured by the acid or basic open-hearth process or by the acid Bessemer process. It is not intended to apply to rolled steel bars or hard-drawn steel wire that have been subjected to any form of manipulation or treatment after being rolled or drawn which has the effect of altering the characteristics of the steel.

Institute of Chemistry and Metallurgy. General Metallurgy. H. Thyssen. (Revue Universelle des Mines, 1938, vol. 14, Feb., pp. 139–145). An account is given of the metallurgical laboratories of the University of Liège.

METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 289 A–290 A)

Modern Microscopy in Railway Work. A. Salmony. (Railway Gazette, 1938, vol. 68, Jan. 7, pp. 19–21). The author describes certain metallographic microscopes of advanced or special design. Reference is made to the " Orthophot " polarising microscope and to various types of camera microscopes.

A New Light Source for Microscopy. H. Wrighton. (Journal of the Royal Microscopical Society, 1937, vol. 57, Dec., pp. 260–261). A description is given of the use of the " Osira " high-pressure mercury discharge lamp as a source of light for microscopy; for this purpose the outer bulb of the lamp is removed, the discharge unit being used alone. The optical characteristics of the light and its particular advantages are briefly discussed.

Concerning the Application of Fluorescence-Analysis Methods in Metallography. R. Mitsche. (Berg- und Hüttenmännische Monatshefte, 1938, vol. 86, Jan.–Feb., pp. 12–14). Difficulties associated with the observation of fluorescence phenomena in metallic specimens under the microscope are said to have been overcome by Haitinger, who, in conjunction with the firm of C. Reichert, has developed an entirely satisfactory fluorescence microscope. This instrument is used in conjunction with a source of ultra-violet light and is capable of very high magnifications. Reference is made to the greenish fluorescence of Cr_7C_3 and to the yellow-green fluorescence of the Cr_4C solid solution; the reactions of inclusions to ultra-violet light are also briefly mentioned. While phenomena of this type are relatively rare in the technically important metallic systems, nevertheless, valuable information may often be obtained by the employment of the fluorescence technique. The preparation of specimens is briefly described. The rapid qualitative analysis of non-metallic inclusions in metals is possible. Whereas certain compounds such as ferric or ferrous oxide and manganous oxide yield no noticeable fluorescence in the untreated state or when treated with mineral acids, it is noted that certain organic acids, such as acetic or formic acid, acquire fluorescent properties after remaining in contact with these substances for periods of greater or less length.

Metallography : A New Technique. B. Chalmers and W. E. Hoare. (Nature, 1938, vol. 141, Mar. 12, p. 475). The authors present a brief account of the use of their interference-fringe technique in metallographic investigation. In general it may be applied to the study of any action which may give rise to characteristic differences of level in a surface.

Electron Diffraction as an Aid in the Investigation of Metallic Surfaces. T. Schoon. (Metallwirtschaft, 1938, vol. 17, Feb. 25, pp. 203–207). The author refers briefly to the use of the electron-diffraction technique in studying metallic surfaces, outlines the experimental procedures suitable for the purpose, discusses general and special features determined by these methods concerning the oxide films on pure metals and alloys and the form of mechanically worked—particularly polished—surfaces, and in conclusion considers the surface peculiarities of metallic catalysts.

Results, New Possibilities and Limitations of the Magnetic Testing of Materials. W. Schirp. (Stahl und Eisen, 1938, vol. 58, Mar. 3, pp. 235–240). The author describes various modifications of the magnetic testing method and indicates the particular uses and limitations of each procedure. It is pointed out that the magnetic method is sensitive not only to actual imperfections in the material but also to non-uniformity of mechanical working and heat treatment; the use of a separate test-piece as a reference body is discussed. Beside the magnetic-powder method, a magnetic-induction method is described and its particular uses considered. A new apparatus dependent on the effects of eddy currents induced in the test-pieces is described; it is applicable to the testing of both ferrous and non-ferrous tubes and bar.

Control by X-Rays of a Welded Bridge on a German Motor Road. F. Guyot. (Ossature Métallique, 1938, vol. 7, Feb., pp. 72–84). The author summarises German standard specifications regarding the examination by X-rays and gamma rays of welded structural steel work, considers this system of control as applied to welded bridges and notes certain typical defects in welded joints. In conclusion a detailed account is presented of the equipment and technique employed for testing welded joints of bridges on German motor roads in this way.

Reticular Structure of Iron Alloys. B. E. Volovik. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 75–76). (In Russian). The author describes a characteristic network structure observed in massive polyhedral austenite in forged high-speed steel maintained at 1200° C. for 6–8 hr. and then quenched.

The Structure and Hardness of Electrolytic Chromium. M. Cymboliste. (Electrochemical Society, Apr., 1938, Preprint No. 9). The author notes the difficulty encountered in finding a suitable etching reagent for the metallographic study of chromium. The anomalous behaviour of electrodeposits of the metal is commented upon; the crystal structure is exceedingly minute and even at high magnifications is not readily observed, while numerous inclusions serve to mask the true crystal structure. On the basis of the three hundred specimens examined by the author it is concluded that a certain analogy exists between the well-known structure of other electrolytically deposited metals and that of chromium deposited from chromic acid baths in spite of the frequent presence

of inclusions which are generally orientated at right angles to the base. Changes in bath composition or the conditions of deposition affect the structure and hardness of the deposit, a change in structure corresponding to a change in hardness ranging from 400 to 1,200 Brinell.

Martensitic Grains in Rapidly-Cooled Ingot Iron and Mild Steel. B. Jones and N. Gray. (Iron and Steel Institute, May, 1938; this Journal, p. 327 P). Two ingot irons and a mild steel were cooled at different rates from controlled temperatures, including the critical range; the mechanical properties were determined and the results correlated with the microstructures. There is a well-defined range of temperature in both ingot iron and mild steel which produces a marked embrittlement on quenching from these temperatures. Low impact values found in mild steel rapidly cooled from temperatures coinciding with the Ac_1 point and above it are due to the presence of martensitic grains, the characteristics of which are illustrated and discussed. Reference to the work of other investigators is given. The brittle range in rapidly cooled ingot iron occurs only in the upper temperature range of the ferrite-austenite zone of the equilibrium diagram, and is confined to temperatures of 875–900° C. Martensitic areas formed by quenching from temperatures lower than these do not cause embrittlement. This is due to the relatively small volume of austenite formed before quenching. Heating to the temperature range stated results in the spreading of the austenite areas, and on rapid cooling the martensitic areas formed are spread over a larger area and by dissociation interfere with the grain boundaries of the ferrite, giving rise to very low notched-bar impact values. A more precise explanation for the peculiar structures found by other workers in rapidly-cooled ingot iron is given. A complete analysis of the materials used is given, including gases and non-metallic inclusions. An appendix by N. Gray and M. C. Sanders describes the method used for the determination of oxygen. The main features include the solution of the steel in molten aluminium in a reducing atmosphere, using apparatus readily available in a steelworks laboratory. The results obtained, even on killed steels, compare favourably with those produced by the more expensive method of hot extraction *in vacuo*.

Analytical Expression of the Granulation Process. A. Markaryantz. (Metallurgist, Russia, 1937, vol. 12, No. 4, pp. 137–141). (In Russian). The author discusses the concepts of Gaev on the kinetics of grain growth, and the calculation of grain size in steel.

Influence of Pouring Time and the Addition of Aluminium on the Grain Size of Steel. I. Fetchenko-Tschopivski and T. Palmrich. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 405–408). The authors describe an investigation of the effect of ladle additions of aluminium, pouring time and hot-working on the grain size of a 0·45% carbon basic open-hearth steel as determined by the McQuaid-Ehn method. The results obtained by this technique are

compared with those obtained by the examination of the fracture of quenched specimens. The effect of pouring time and of aluminium additions on grain growth are also dealt with. Tabular data are presented.

Concerning the Primary Crystallisation of Cast Iron. W. Patterson. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Mar., pp. 463–465). The solidification of hypo-eutectic cast irons commences with the separation of dendritic crystals of solid solution; at the same time binary and poly-eutectics solidify. The ternary phosphide eutectic forms around spherical islands of binary eutectic. The arrangement of phosphide, sulphide, titanium nitride and titanium carbide inclusions is discussed.

Laws of the Austenite $\rightleftharpoons$ Pearlite Transformation. S. A. Kazeev and M. B. Reznik. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 43–50). (In Russian). The authors apply their law relating the quantity of residual austenite to time to eight steels containing from 0 to 6·7% of chromium. The formula which they derived to express this relationship is shown to be valid; the transformation of austenite to pearlite actually commences before the break in the cooling curve and proceeds, not at one definite temperature, but within a certain interval. The so-called "critical point"—Ar_1—represents only the temperature at which the transformation velocity attains a maximum. The velocity of transformation is 13·7% by weight of the austenite per second at an initial cooling temperature of 850° C. and 1·10% for an initial temperature of 925° C. The transformation velocity is a complex function of the chromium content with a minimum at 0·9% of chromium.

Isothermal Transformation of Austenite. E. S. Tovpenetz. (Metallurgist, Russia, 1937, vol. 12, No. 2, Feb., pp. 61–65). (In Russian). Three steels containing (*a*) 0·35% of carbon, 1·11% of chromium, 0·15% of nickel, 0·27% of molybdenum and 0·13% of vanadium, (*b*) 0·32% of carbon, 0·70% of chromium, 3·37% of nickel and 0·35% of molybdenum, and (*c*) 0·37% of carbon, 2·44% of chromium, 1·38% of nickel and 0·35% of molybdenum, were each heated to 860° C. for 30 min. and then placed in a magnetometer furnace. After the austenite had been allowed to decompose for some time, the samples were quenched and their microstructures and hardness values determined. The greater the degree of the decomposition of the austenite before quenching the less homogeneous was the microstructure and the lower the hardness. Transformation begins at the surface of individual crystals and proceeds non-uniformly for different crystal grains. The degree of hardness which the material is capable of acquiring and its final structural homogeneity depend, in step-hardened specimens, on the degree of decomposition undergone by the austenite before quenching and on the thermal stress occasioned by this process; rapid cooling promotes increased hardness, homogeneity and cooling stresses.

The Use of the Potentiometer for the Determination of Temperature-Time Curves in Thermal Analysis. C. Perrier and A. Bellanca. (Atti della Reale Accademia Nazionale dei Lincei, Rendiconti Scienze fisiche, matematiche e naturali, 1937, vol. 26, Nos. 7–8, pp. 245–521). The authors note the disadvantages of the ordinary method of determining temperature-time curves, particularly at higher temperatures, by plotting directly the intensities of the current developed by the thermocouple from galvanometer readings and discuss a potentiometric method of very high accuracy. The apparatus used is described in detail and the results obtained are critically reviewed.

Phase Diagrams for Systems of Three and more Components. I. F. Afonskii. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 49–54). (In Russian). The author suggests a development of the triangular representation of ternary compounds to cover systems containing five or more components, which might be represented by regular polygons with five or more sides. The method of determining the composition of a mixture corresponding to a given point in such a polygon is considered at length.

Types of Metals and the Basic Forms of Binary Systems. E. Kothny. (Metallwirtschaft, 1938, vol. 17, Feb. 25, pp. 207–211). The author discusses the classification of metals into two main groups, one containing those metals characterised by the absence of transformations, and the other those metals undergoing transformations; this latter class is further subdivided according to whether one, two, or more transformations are concerned. Binary systems are also divided into two main groups according to their behaviour in the liquid state, namely, those exhibiting discontinuities in miscibility and those exhibiting no discontinuities in miscibility. Each of these groups is further subdivided according to the number of intermetallic compounds occurring in the system and according to the behaviour of each system on melting. The author presents a classification of binary alloys according to this system in tabular form.

Alloys of the Iron-Beryllium System. I. S. Gaev and R. S. Sokolov. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 42–48). (In Russian). The authors discuss the results of an investigation of the iron-beryllium system with beryllium concentrations from 0 to 16%. The diagram exhibits a γ-loop extending to 0·3–0·4% of beryllium only. The solubility of beryllium in α-iron is 4·5–5% at 20°, increasing to 7·5–8% at 1150° C.; the eutectic contains 10% of beryllium and freezes at 1150° C. The lattice constant of α-iron is decreased by beryllium. The compound $FeBe_3$ has a hexagonal lattice. Iron alloys containing more than 0·5% of beryllium are brittle. In general the alloys may be nitrogen-hardened and acquire a high surface hardness and resistance to atmospheric corrosion. The velocity of diffusion of beryllium into iron can be represented by an exponential function which is critically discussed.

The Iron-Manganese-Silicon System. E. Jänecke. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Feb., pp. 409–411). The author discusses the diagram of the ternary system iron-manganese-silicon as proposed by Vogel and Bedarff and comments upon the interpretation advanced by these workers of certain fields in this diagram. (*See also* Journ. I. and S.I., 1937, No. II., p. 161 A).

Constitution of Alloys of Iron with Silicon and Aluminium. G. G. Urasov and A. V. Shashin. (Metallurgist, Russia, 1937, vol. 12, No. 4, Apr., pp. 27–41). (In Russian). The authors discuss the results of an investigation of the iron-aluminium system at aluminium concentrations of 30–61%, and of a similar investigation of the ternary system with silicon. The technique employed in the examination is discussed and the binary and ternary diagrams concerned are considered at length.

CORROSION OF IRON AND STEEL

(Continued from pp. 291 A–293 A)

Corrosion Tests. W. O. Kroenig. (Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 53–62). The author discusses the factors influencing the resistance of metals to chemical attack, more particularly in laboratory corrosion tests, and stresses the necessity of standardising experimental conditions in order to avoid erroneous or inconsistent results. Electrochemical tests, gravimetric and mechanical tests, tests based on the determination of variations in the volume of the gas evolved or absorbed during the progress of corrosion, and special technical and accelerated corrosion tests are then described at length.

The Correction Coefficient $W_p/(W_p + W_s) = R_A/(R_A + R_K)$. W. J. Müller. (Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 63–66). The author comments on the equation of Akimov and Tomaschov expressing the "total potential" of a binary system, namely:

$$V_{MN} = V_A + (V_K - V_A)\frac{R_A}{R_A + R_K}$$

and states that this is identical with an expression he himself derived to signify this quantity prior to the publication of these two workers' results. It is, moreover, shown that the "correction factor" K for effects due to polarisation occasioned by surface films derived by Akimov and Tomaschov is identical with that previously postulated by Müller.

On the Theory of Metallic Dissolution. IV. M. Straumanis. (Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 67–77). The author presents a discussion upon the "difference effect" of Thiel and Eckell, indicates the method by which formulæ for expressing it are derived and considers the experimental verification of the phenomenon. The difference effect supports the electrochemical theory of metallic corrosion. It is shown that Müller's hypothesis concerning the effect of a surface film of variable properties is in no way opposed to the "local couple" theory advanced by the author.

Concerning the Potential of Metals which Dissolve Anodically or as the Anodes of Local Couples. W. J. Müller. (Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 77–80). The author discusses the work of Straumanis (*see* previous abstract). Extensive work by the author on the anodic passivity of metals has clearly shown that the potential of a metal undergoing anodic dissolution is independent of the current density up to very high current densities, and that polarisation occasioned by passivity of the surface film is to be attributed solely to the resistance at pores in this film.

On the Theory of Metallic Dissolution. V. M. Straumanis. (Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 81–83). The author comments upon Müller's interpretation of the effects of the surface film in connection with the electrochemical theory of corrosion and shows that the local-couple theory is not opposed to Müller's hypotheses. The local-couple theory is summarised.

Results of Recent Investigations on the Relationship between Corrosion and Local Couples. W. J. Müller. (Gesellschaft für Korrosionsforschung und Werkstoffschutz, 1937: Korrosion und Metallschutz, 1938, vol. 14, Feb., pp. 49–53). The author presents a general account of the electrochemical theory of corrosion and discusses, in particular, the rôle of local couples in corrosion phenomena.

The Rate of Corrosion of Unalloyed Steel in Air. K. Daeves and K. Trapp. (Stahl und Eisen, 1938, vol. 58, Mar. 3, pp. 245–248). The rate of corrosion of steels containing 0·2% of copper in industrial atmospheres is about 600 g. per sq. m. per year, and in rural atmospheres about 150 g. per sq. m. per year. Urban atmospheres give a value approximately equal to the mean of these two. Steels containing 0·02% of copper corrode at the rate of 1200 g. per sq. m. per year in industrial atmospheres and at the rate of 250 g. per sq. m. in country air. The corrosive effect of industrial atmospheres is about four times that of pure country air. By raising the copper from 0·02 to 0·2% the loss by corrosion is reduced by about half. As, however, copper above 0·15% produces no appreciable further diminution in loss of weight by corrosion, a copper content even of this order reduces the rate of corrosion to 80% of that of a steel containing only 0·05%. If in conjunction with a copper content of 0·15% the phosphorus content of a steel is raised above 0·06%, loss by corrosion is still further reduced. By raising the copper content of all the steelwork in Germany which is normally not protected or is used in the galvanised state, a saving of 20,000 tons of steel could be effected annually.

The Corrosion of Metals in Solutions Considered as an Electrochemical Phenomenon. W. J. Müller. (Chimie et Industrie, 1938, vol. 39, Jan., pp. 31–39). The author considers the general significance of corrosion phenomena and discusses briefly the different methods employed to study them. The work of De la Rive on the dissolution of zinc in sulphuric acid of various concentrations and his hypothesis that chemical attack in this case was due to the formation of local couples are discussed, together with the investigations of Palmær. A simple explanation is advanced for the fact that the potential of a metallic plate during the process of dissolution is always more noble than the true metallic potential according to Nernst. Concerning the effect of oxidising depolarisers the author shows that these substances operate by their influence on local couples.

Corrosion of Some Alloys by Solutions of Ammonium Salts in

Liquid Ammonia. L. F. Audrieth and T. E. Franks. (Metals and Alloys, 1938, vol. 9, Feb., pp. 51–52). The authors refer briefly to the properties and applications of solutions of ammonium salts in liquid (anhydrous) ammonia. Reference is made to the uncertainty surrounding the action of Diver's solution (a concentrated solution of ammonium nitrate in liquid ammonia) upon iron and steel. Experiments were made to test the comparative resistance of alloys to liquid-ammonia solutions of various ammonium salts. Chromium-nickel steels and high-chromium steels are resistant to attack by such solutions of ammonium nitrate and chloride while iron and other types of steel are attacked. The first-mentioned groups of steel are, however, attacked by a solution of ammonium thiocyanate.

Influence of Composition and Treatment on the Rate of Acid Attack on Mild Steel. C. A. Edwards, D. L. Phillips and D. F. G. Thomas. (Iron and Steel Institute, May, 1938; this Journal p. 273 P). This investigation deals with the influence of phosphorus, carbon, sulphur and copper on the rate of attack by 6% sulphuric and 2% citric acids on mild steels, both in the annealed and in the heavily cold-rolled conditions.

The steels were made in quantities of about 24 lb. in a high-frequency induction furnace under carefully controlled conditions, and chill-cast in the form of thick plates suitable for rolling into packs of thin sheets, as in ordinary tinplate practice.

The Atmospheric Corrosion of Galvanised Iron Wire and its Bearing on Specification Testing. C. E. Richards. (Iron and Steel Institute, May, 1938; this Journal p. 127 P.). The question of specification testing is of great importance to the large user of galvanised wire. In Britain the copper sulphate dipping test (Preece test) still enjoys favour.

It is shown that the Preece test is of little value in determining the resistance of a wire to atmospheric corrosion. It discriminates unfairly against some coatings and flatters others. The predominating factor in the life of galvanised wire in a given atmosphere is the thickness of the zinc envelope, and characteristics such as the purity and ductility of this coating are of minor importance.

The lives to be expected of wires in different types of atmosphere are calculated, and estimates are given of the cash value of adequate galvanising for a typical wire structure. Savings of the order of 25% are shown for this structure, in which the cost of wire is only about 10% of the original cost of erection. The economy is due to the saving on labour costs resulting from fewer renewals.

The wide disparity between the rates of failure in industrial and rural areas is demonstrated, and the fact that under certain circumstances even bare iron patches are of little importance is shown.

Laboratory investigations have given interesting results, but have been of little help in suggesting specification tests.

A plea is made for discarding the Preece test on wires in favour

of a stripping test. The ductility test as at present specified (B.S.S. 443) is useful and should be retained.

Passivity as Induced by Pigments. U. R. Evans. (Oil and Colour Chemists' Association: Oil and Colour Trades Journal, 1938, Mar. 18, pp. 813–814). After remarking that protective painting was often regarded as a simple waterproofing process intended to exclude all corrosive media from the metal treated with the paint, the author observes that some classes of coatings are initially pervious or tend to become so yet they prevent the corrosion of iron by keeping the metal passive. The two types of paint coats are differentiated. For the protection of steel against atmospheric corrosion, red lead in the priming coat covered with other coats based on iron oxide give excellent results. For marine purposes, the action of sulphides on the protective qualities of red lead require investigating. Priming coats based on metallic lead and also suitable mixtures of red lead and graphite could give good results. The importance of removing scale is discussed, together with the protective value of pigments capable of inducing passivity in the iron to which they were applied. Among the pigments discussed are chromates and metallic lead; the mechanism of their action is considered in some detail. Reference is made to the work of J. C. Hudson for the Corrosion Committee of the Iron and Steel Institute.

Concerning a Cause of Pitting on the Inner Side of Steel Ships' Bottoms. (Stahl und Eisen, 1938, vol. 58, Mar. 10, p. 281). A summary is presented of an article by Daeves and Ristow which appeared originally in Z. Binnenschiff, 1938, No. 1. The authors of this paper describe the corrosion occurring on the inner side of the steel bottoms of vessels employed for the transport of roasted pyrites which, whilst not in direct contact with the steel bottom, nevertheless gave rise to fines which passed through fissures in the false bottom and came into contact with water on the inner side of the true bottom. Separation of spongy copper occurred with consequent attack of the steel. Various expedients to prevent this type of corrosion are described, including that of adding inhibitors to the water in the ship's bottom. Certain protective films, vaseline, for example, are not effective protective agents in the presence of concentrated corrosive solutions such as may occur under the conditions described.

Determination of Magnetic Iron Oxide as a Measure of Corrosion of Boiler Superheater Elements. R. C. Ulmer. (Industrial and Engineering Chemistry, Analytical Edition, 1938, vol. 10, Jan. 15, p. 24). The author describes a method for estimating magnetic iron oxide suitable for use when investigating the corrosion of steam superheater tubes. The specimen is immersed in concentrated hydrochloric acid containing 2% of antimony oxide and 5% of stannous chloride and the loss in weight is determined. Results are presented which indicate that the loss in weight due to attack on the steel itself is low and constant and may be duly corrected for.

ANALYSIS

(Continued from pp. 224 A–226 A)

Analytical Chemistry. Huybrechts. (Revue Universelle des Mines, 1938, vol. 14, Feb., pp. 151–155). An account is presented of the equipment for chemical analysis in the analytical laboratory of the Department of Chemistry and Metallurgy at the University of Liège.

Methods of Analysis on very Small Samples and their Application to Metallurgical Investigations. A. Portevin and A. Leroy. (Académie des Sciences, Feb. 14, 1938: Génie Civil, 1938, vol. 112, Mar. 5, p. 214). The authors refer briefly to the determination of manganese, chromium and phosphorus by micro-chemical methods. The utilisation of this technique in the chemical analyses involved in the study of hereditary or acquired chemical heterogeneity, of metallic diffusion and of superficial changes occasioned by corrosion phenomena, for example, is commented upon shortly.

On the Preservation of the Standard Solution of Potassium Permanganate. T. Katô. (Journal of the Chemical Society of Japan, 1927, vol. 48, p. 408: Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Dec., pp. 297–302). In order to prepare a standard solution of potassium permanganate the ordinary commercial salt may be dissolved in ordinary distilled water, the solution boiled, left to stand for a day, filtered through asbestos or glass and preserved in a steamed bottle covered with black paper. A solution prepared in this way is stated to remain unchanged for as long as a year. Specially pure materials or distilled water, the use of preservatives and of special containers is unnecessary.

The Photometric Determination of Molybdenum in Steel. K. Dietrich and K. Schmitt. (Metallwirtschaft, 1938, vol. 17, Jan. 28, pp. 88–89). The authors describe a colorimetric method for the estimation of molybdenum in steel in which ammonium thiocyanate is used in conjunction with stannous-potassium chloride as a reducing agent. With solutions of known alkali content absolute values are obtained as the loss in colour is linear with respect to time. Graphical and tabular data are presented.

Determination of Manganese, Nickel and Phosphorus in Iron and Steel. W. M. Murray and S. E. Q. Ashley. (Industrial and Engineering Chemistry, Analytical Edition, 1938, vol. 10, Jan. 15, pp. 1–5). The authors describe a technique (employing a Zeiss Pulfrich step-photometer) for the rapid photometric estimation of manganese, nickel and phosphorus in iron and steel. Four to six determinations of any of these elements may be made in an hour; both reproducibility and accuracy are high and at least equal to those obtained with most routine determinations.

The Determination of Iron with Mercaptoacetic Acid. H. W. Swank and M. G. Mellon. (Industrial and Engineering Chemistry, Analytical Edition, 1938, vol. 10, Jan. 15, pp. 7–9). The authors consider the suitability of mercaptoacetic acid as a reagent for the colorimetric determination of iron. The effect of common cations and anions and general conditions affecting the method are discussed; it is concluded to be superior to other colorimetric procedures for estimating iron.

Importance of Hydrogen-Ion Concentration for the Estimation and Separation of Metals by the Oxine Method. H. Gotô. (Journal of the Chemical Society of Japan, 1933, vol. 54, p. 725; Science Reports of the Tôhoku Imperial University, 1937, vol. 26, Dec., pp. 391–413). The effects of the *p*H value of the solutions on the quantities of precipitate obtained with metallic solutions by means of *o*-hydroxyquinoline were investigated for aluminium, zinc, cadmium, nickel, manganese, cobalt, titanium, uranium, thorium, lead, calcium, magnesium, iron, copper and bismuth. The *p*H ranges for quantitative precipitation were determined. The *p*H ranges examined covered both acid and alkaline solutions. Curves are presented giving the *p*H ranges in which quantitative precipitation and separation from accompanying metals of any given metal may be carried out.

On the Separation of Iron, Aluminium, Chromium, Uranium, Zirconium and Titanium in the Presence of Manganese, Cobalt, Nickel, Calcium, Strontium, Barium, Magnesium and the Alkalis by Means of Pyridine. E. A. Ostroumov. (Annales de Chimie Analytique, 1938, vol. 20, Jan. 15, pp. 9–12). The author recommends a new method for the separation of iron, aluminium, chromium, uranium and titanium from cobalt, manganese, nickel, calcium, strontium, barium, magnesium and the alkalis, based on the quantitative precipitation of the metals first named by pyridine in faintly acid solution.

Control of the Gas Content in Liquid Metals. V. A. Danilov. (Metallurgist, Russia, 1937, vol. 12, No. 4, pp. 134–136). (In Russian). The author describes a simple method of estimating the gas content of liquid alloys prior to casting. Samples are cast either on to an iron sheet or into a small cylindrical mould. The investigations reported were conducted on non-ferrous metals.

The Complete Analysis of Chromite. C. F. J. Van Der Walt. (Analyst, 1938, vol. 63, Mar., pp. 176–179). The author outlines a procedure for the analysis of chromite in which the preliminary fusion of the mineral is carried out with potassium pyrosulphate. Reference is made to the behaviour of certain silicates in the pyrosulphate fusion. Part of the silicates may be decomposed but the liberated silica is not rendered insoluble.

The Exact Quantitative Estimation of Ferric Oxide and Sulphide Sulphur in Basic Slags. E. Maurer and F. Haderer. (Iron and Steel Institute, May, 1938). Brief references are made to the

literature. The authors made twenty-two melts of synthetic sulphur-containing slags to determine the sulphide sulphur content, first without tin, and secondly with tin added to the dissolving acid; these showed that the error increases with the ferric oxide content of the slag. The latter was determined on the one hand indirectly by the method of O. Quadrat and on the other hand directly by that of W. Faber. In all the experiments the iron oxide content was found to be smaller when using the latter method than with the former, so that even an addition of mercuric chloride, as recommended by Faber, fails to prevent the nascent hydrogen sulphide produced by the acid solution from reacting with the iron oxide. It is further shown by direct experiment that the method of O. Quadrat does in fact yield perfectly accurate values for the iron oxide content.

On the Use of the Spectroscope for the Rapid Control of Steel. H. Kjerrman, G. Phragmén and B. Rinman. (Jernkontorets Annaler, 1937, vol. 121, No. 12, pp. 703–710). The "Spekker Steeloscope" by Hilger of London was found to be very useful for the rapid determination of the composition of alloy steels. It is, in general, possible to distinguish with absolute certainty between two steels when the ratio of the contents of the elements searched for is 1 : 2. In routine work a trained observer may make up to 150 analyses per hour.

Some Helpful Accessories in Practical Spectrographic Analysis. J. S. Owens. (Metals and Alloys, 1938, vol. 9, Jan., pp. 15–19). Descriptions are given of four useful accessories for practical spectrographic analysis: Graphite electrodes purified by high-temperature electric heating *in vacuo*; alignment pointer for the spectral source; alternating-current arc source; graphical plate calculator for the conversion of microphotometer readings into percentage concentrations.

The Spectrograph in the Iron Foundry. H. B. Vincent, R. A. Sawyer and A. M. Sampson. (Metals and Alloys, 1938, vol. 9, Feb., pp. 27–32). The authors present an account of the theory and practice of the quantitative spectrographic analysis of cast iron. The complete analysis of a sample occupies eight minutes, the results obtained being in general more reliable than those yielded by chemical methods. The routine procedure described is in operation at the Campbell, Wyant and Cannon Foundry Co., Muskegon, Michigan.

A Semi-Micro Kjeldahl Method for the Determination of Nitrogen in Coal. A. E. Beet and R. Belcher. (Fuel in Science and Practice, 1938, vol. 17, Feb., pp. 53–55). A semi-micro technique for the determination of nitrogen in coal by the Kjeldahl method is described. The test can be carried out in 30 min.; it minimises certain defects inherent in the macro-method, namely, the emission of oxides of sulphur and the possibilities of "bumping."

Determination of Carbon Monoxide in Products of Combustion of Town's Gas. E. C. Roberson. (Journal of the Society of Chemical Industry, 1938, vol. 57, Feb., pp. 39T–43T). Anomalies occurring in the determination of carbon monoxide in products of combustion

by the iodine pentoxide method are traced to four main causes: Carbon monoxide present in the nitrogen used for purging the sample from the reaction train; non-removal of acid spray from the washing tubes; incomplete reaction between the carbon monoxide and the iodine pentoxide; large variations in the times required to sweep similar samples through different trains. A new apparatus and technique are introduced to eliminate these disturbing effects and possible sources of error in the new method are investigated and assessed.

Determination of Small Quantities of Oxygen in Gases and Liquids. I. J. W. MacHattie and J. E. Maconachie. (Industrial and Engineering Chemistry, Analytical Edition, 1937, vol. 9, Aug. 15, pp. 364–366). A method of estimating the free oxygen in gaseous mixtures and in liquids consists in exposing to the sample to be tested a metallic copper surface wetted with a solution of ammonium chloride in ammonium hydroxide. The oxide produced is washed off with the same solution and the copper in it estimated colorimetrically; by the use of a conversion factor the oxygen content is determined from this.

The Determination of Sulphur in Solid Combustibles by Burning in a Current of Oxygen. A. Seuthe. (Archiv für das Eisenhüttenwesen, 1938, vol. 11, Jan., pp. 343–344). A method is described for estimating the total sulphur content of solid combustibles by burning in a current of oxygen. It is applicable to bituminous coals, coke and lignite. A porcelain tube furnace provided with Silit heating elements and capable of operating at 1200° C. for prolonged periods is required together with a specially developed absorption system of relatively simple form. A determination occupies 8–10 min.

Platinised Silica Gel as a Catalyst for Gas Analysis. K. A. Kobe and W. I. Barnet. (Industrial and Engineering Chemistry, Analytical Edition, 1938, vol. 10, Mar. 15, pp. 139–140). Methane and ethane are completely oxidised when passed over a platinised silica gel catalyst with excess oxygen at 610° C. The catalyst-tube method may be used for the determination of hydrogen and hydrocarbons, singly or together, by the use of the correct oxidation temperature.

High-Vacuum Gas-Analysis Apparatus. E. C. Ward. (Industrial and Engineering Chemistry, Analytical Edition, 1938, vol. 10, Mar. 15, pp. 169–171). The author describes a simple method for the accurate fractional analysis of light hydrocarbons using a vacuum of the order of 1 mm. of mercury.

Suggested Improvements in the Ultimate Analysis of Liquid Fuels by the Semi-Micro Method. M. Richter and M. Jaeschke. (Angewandte Chemie, 1938, vol. 51, Mar. 12, pp. 147–148). The authors describe an improved apparatus for the determination of carbon and hydrogen in liquid fuels containing sulphur, nitrogen and halogens by the method of Meulen and Heslinga. Various sources of error due to back-distillation, pre-condensation and other phenomena are said to be avoided in the new apparatus. Experimental results are presented in tabular form.

BOOK NOTICES

(Continued from pp. 294 A–298 A)

BRITISH CHEMICAL PLANT MANUFACTURERS' ASSOCIATION. "*Official Directory, 1938.*" 8vo. pp. 170. London, 1938: The Association.

This useful book of reference forms a complete directory of the British Chemical Plant Manufacturers' Association for the guidance and benefit of chemical manufacturers and other users of chemical plant. It contains, in addition to the directory of Members, a classified list of products and services, and particulars of proprietary and trade names and marks.

HARTLEY, L. A. "*Elementary Foundry Technology.*" Second Edition. Revised by E. Bremer and P. Dwyer. 8vo. pp. xii + 377. Illustrated. Cleveland, Ohio and London, 1937: Penton Publishing Co. (Price 13*s.*)

This book covers a course of instruction designed to conform to the Minimum Standards of Four-Year Apprenticeship in the United States of America. The original text was prepared by the National Founders Association in 1928 under the direction of L. A. Hartley, at that time the Director of Education of the Association. It has now been revised and brought up to date by E. Bremer and P. Dwyer, who are respectively the metallurgical and engineering editors of *The Foundry*. As in the preparation of many other modern American books, a large number of people have co-operated in the work. The general nature of the contents was in the first instance decided on by a committee of men prominent in the foundry industry. The first edition was prepared by the editor in collaboration with a number of representatives of the industry, experts in education, professors and instructors in foundry work, &c. In preparing the revised edition the assistance of several experts has again been obtained, and in general it may be said that every effort has been made to ensure the accuracy and completeness of the work in so far as this can be done by utilising available sources of information and enlisting the assistance of a body of men qualified to deal with different aspects. The object of the book is to provide a systematic course of technical instruction for foundry apprentices, and it is intended to be used in courses of training designed to meet their needs. It deals in the first place with some elementary aspects of physics and chemistry, and the first 147 pages are occupied with six sections devoted respectively to substances and their structure, physical properties, oxidation, reduction and combustion, force and motion, application of force, and the mechanics of fluids. The seventh section deals with the effects of the usual elements on iron, and this is followed by a section describing the production of pig iron in the blast-furnace and the operation of the cupola. The remaining sections (pp. 227–353) are concerned with various aspects of foundry work, namely, elementary problems in steel foundry production and brass melting, sands, gates and risers, and moulding machines. Each section is divided into a number of chapters, of which there are seventy-five. At the end of each chapter there is a list of questions on the subject-matter of that chapter, and references are given to sources of further information. At the end of the book there is a glossary of foundry terms and a bibliography.

J. M. ROBERTSON.

KRUSCH, P. "*Die Metallischen Rohstoffe, ihre Lagerungsverhältnisse und ihre wirtschaftliche Bedeutung. 2 Heft. Molybdän, Monazit, Mesothorium.*" 8vo. pp. iv + 87. Illustrated. Stuttgart, 1938: Ferdinand Enke Verlag. (Price 6 RM.)

The first volume of this series was reviewed in the last volume of the *Journal*, and the present book is written on exactly similar lines. The first part deals exclusively with molybdenum, and the second with monazite and mesothorium. An historical account of the metals dealt with precedes a description of their mode of occurrence in minerals, and thereafter the principal ore deposits of the world are considered separately. Of the molybdenum-producing countries, the United States of America is by far the most important, and a good description is given of the deposits at Climax, Colorado, a large-scale geological map of the region being included. Other areas are dealt with in less detail, and a description is given of the German sources of the metal, including the uneconomic deposits of wulfenite near Garmisch, and the only present source of production, the Mansfelder schists. The extraction and uses of molybdenum are described at some length, and the section concludes with some statistics of world production, market conditions, and price levels. Monazite sand and mesothorium are dealt with on a similar plan, the description of the monazite deposits in Brazil, Ceylon and Travancore being accompanied by small-scale maps indicating the productive areas. The description of the properties of mesothorium includes some information on the radioactive properties of the metal and its derivatives, and a table is given showing the products obtainable from monazite sand and their industrial and scientific uses.

STEPHEN L. ROBERTON.

SALMON, E. H. "*Materials and Structure.*" A Text-book for Engineering Students. 8vo. Illustrated. Vol. I. "*The Elasticity and Strength of Materials.*" pp. x + 638. 1931. (Price 18*s.*) Vol. II. "*The Theory and Design of Structures.*" pp. viii + 796. 1938. (Price 32*s.*) London, New York and Toronto: Longmans, Green and Co.

The appearance of the second volume of this work completes the author's original plan of preparing a comprehensive and systematic text-book dealing with the strength of materials and the theory of structures. The division of the material has been carried out in such a way, however, that each volume is complete in itself, and just as the first volume has proved an extremely useful work during the seven years that the second has been in preparation, so the second may be used as a complete and independent work by those who are sufficiently conversant with the ground covered by the first. Most engineers will already be familiar with the first volume, however, and will be anxious to acquire the second, and those whose interest is first aroused by the appearance of the second volume will no doubt hasten to obtain the other. The first volume is divided into two parts, which deal respectively with elastic stress and strain and the properties of materials as determined by experiment. The first part covers the usual ground in a thorough manner, and contains in addition two chapters on the mathematical theory of elasticity. A number of well-chosen examples with answers are a good feature of this part. The second part also covers the usual ground, *i.e.* the properties of engineering materials

and testing, including impact, fatigue and creep testing. An interesting addition is a chapter on metallography, which is designed to introduce the reader to the important field of physical metallurgy. The second volume is primarily concerned with the theory of structures and its application to practical design. It has been planned on a comprehensive basis and carefully arranged. The text is illustrated with many worked examples and practical designs. Special attention is given to the presentation of the principle of least work, and two chapters are devoted to the properties of building materials, *i.e.*, timber, stone, cement, concrete and reinforced concrete. The book as a whole is designed for the use of students studying for engineering degrees and for those entering for the associate membership and membership examinations of the engineering institutions. Owing to its wide scope, the comprehensive way in which the various aspects of the subject are treated, and the extensive lists of references appended to each chapter, it is, however, of great value as a work of reference, and should be of notable service to practising engineers, particularly those engaged in the design of structures. Throughout the work great forethought has been taken in arranging the material, so that the treatment is logical, and in general the work may be said to be extensive, well planned and prepared with the greatest care.

J. M. ROBERTSON.

SIMONS, E. N., and E. GREGORY. "*The Structure of Steel Simply Explained.*" With an Introduction by F. C. Lea. Sm. 8vo. pp. x + 115. Illustrated. London and Glasgow, 1938: Blackie and Son, Ltd. (Price 3*s.* 6*d.*)

This little book is easy to buy and easy to read. It is addressed to those who are not in the habit of reading metallurgical books or journals and is likely to have a wide circulation among them. For these reasons the book is more important than its size suggests. Furthermore, as it represents an attempt to describe briefly and simply a subject that is generally supposed to be difficult to understand, it is an interesting experiment in metallurgical authorship. The book originated in a series of articles in the "Edgar Allen News." One of the authors (E. N. S.), as editor of this journal, became aware that many of those who buy, sell, manipulate and in general have to do with steel were eager for an insight into its structure, but found it difficult to obtain this from the existing literature, which is written by experts for experts or by professors for students. He therefore conceived the idea of studying the subject and trying to explain it as he, a non-technical man, understands it. The appearance of the articles was followed by numerous expressions of interest and appreciation and requests for the publication of the series in book form. From academic and expert sources, however, some criticism was obtained, and the author of the articles wisely decided to have them thoroughly revised by Dr. Gregory before being published as a book. It must be admitted that, in spite of the extensive literature on the constitution and structure of steel, an understanding of the subject is hard to attain, even when the student has a knowledge of physics and chemistry and some acquaintance with other branches of metallurgy. As the experience of the authors and of many others shows, there is a widespread demand for knowledge about this subject among those whose work is concerned with steel but is not of such a nature as to require a full technical training, and it is time that someone provided a book for them. The present volume satisfies the requirements as far as price and size are

concerned, but an experiment such as this must be judged by other standards besides these. If this book is to fulfil the intentions of the authors, it should be possible for a man without a technical training to obtain a general idea of the subject simply by reading this volume. Unfortunately it is difficult to say whether and to what extent this purpose is achieved. A reader who knows the subject already cannot judge how much a layman will understand about it after reading this book. On the other hand, one who does not know the subject before reading the book is not in a position to estimate the extent of his understanding afterwards. The authors claim that the story of steel and its structure is here told for the first time in a simple and straightforward manner, without inaccuracy or misstatement, and in words that the layman can understand. All this is substantially although not entirely true. But the success of the experiment depends mainly on whether the argument is developed from the beginning to the end of the book in such a way that the reader proceeds through the subject step by step, building up a general picture as he goes. In this respect the work is not nearly as good as it might have been, and although a non-technical reader will pick up a lot of information from the book, he will have difficulty in arranging the ideas presented so as to compose in his mind a satisfactory picture of the subject in general. It may therefore be said that the present book is an interesting experiment which fulfils in some measure the intentions of the authors. Furthermore, it indicates that the subject dealt with can be presented briefly and comparatively simply. Should the experiment be repeated, however, much more attention should be given to the arrangement of the material so that the argument will develop logically. Blanks should be filled in and subjects such as X-rays omitted. Finally, the work should be expanded to make the narrative more continuous, for if the prospective readers have any real desire to get a grasp of the subject, surely it will be strong enough to carry them through a book twice this size.

J. M. ROBERTSON.

SOCIETY OF CHEMICAL INDUSTRY. "*Reports of the Progress of Applied Chemistry.*" Vol. XXII. 1937. 8vo. pp. 816. London: Society of Chemical Industry. (Price 7*s.* 6*d.* to Members of the Society, 12*s.* 6*d.* to others).

This annual volume, issued by the Society of Chemical Industry, contains, as usual, reports by leading authorities on the progress in 1937 of applied chemistry. Certain of the sections are of special interest to iron and steel manufacturers and those engaged in the study of ferrous and non-ferrous metallurgy. The reports contained in the present volume are as follows: General Plant, and Machinery, by M. B. Donald and H. W. Thorp; Fuel, by J. G. King; Gas, Destructive Distillation, Tar and Tar Products, by H. Hollings and W. A. Voss; Mineral Oils, by W. W. Goulson; Intermediates and Colouring Matters, by E. H. Rodd, in collaboration with G. M. Holmes, F. Irving, M. Lapworth and R. Fraser Thomson; Fibres, Textiles and Cellulose, by J. B. Speakman, C. S. Whewell and H. A. Turner; Pulp and Paper, by Stephen R. H. Edge; Acids, Alkalis, Salts, etc., by A. J. Prince and F. J. Wilkins; Glass, by A. Cousen; Refractories, Ceramics and Cement, by J. A. Sugden; Iron and Steel, by C. O. Bannister; Non-Ferrous Metals, by Alan R. Powell; Electrochemical and Electrometallurgical Industries, by J. W. Cuthbertson; Oils, Fats and Waxes, by T. P. Hilditch; Paints, Pigments, Varnishes, Resins and Solvents, by Members of the Oil and Colour Chemists' Association; Rubber, by T. L.

Garner; Leather and Glue, by Donald Burton; Soils and Fertilisers, by E. M. Crowther; Sugars and Starches, by Lewis Eynon and J. Hy. Lane; The Fermentation Industries, by R. H. Hopkins, F. W. Norris, and I. A. Preece; Foods, by T. Moran and E. C. Bate Smith; Fine Chemicals and Medicinal Substances, by Edgar Stedman; Photographic Materials and Processes, by H. V. Horton; Sanitation, Water Purification, etc., by J. H. Coste.

SPRATT, H. P. "*One Hundred Years of Transatlantic Steam Navigation, 1838–1938.*" (Board of Education. Science Museum). 8vo. pp. 22. Illustrated. London, 1938 : H.M. Stationery Office. (Price 6*d.*, postage extra.)

This handbook sets forth in very brief outline the history and development of the Atlantic Steam Ferry since the advent of the steamship, and at the same time serves as a Guidebook to the Exhibition which has been assembled in the Science Museum, South Kensington, London. The period covers the transition from wood to iron and from iron to steel as the material for ship construction, and from paddle-wheel to single, twin, triple and quadruple screw propulsion; the change from simple to compound, triple and quadruple expansion reciprocating engines; the development of the Parsons direct drive, single and double reduction geared turbines; and an enormous improvement in passenger accommodation, from the time when Charles Dickens crossed on the first Cunard liner "Britannia" in 1842 to the present standard of comfort in the R.M.S. "Queen Mary." The increase in size of ships can be gauged from the fact that the "Britannia," shorn of her masts and funnel, would fit into the restaurant and foyer of the R.M.S. "Queen Mary."

STOCKDALE, D., and J. DEXTER. "*Clowes and Coleman's Quantitative Chemical Analysis.*" An Intermediate Text-Book. Fourteenth Edition. 8vo. pp. xiv + 617. Illustrated. London, 1938 : J. and A. Churchill, Ltd. (Price 18*s.*)

When a book has reached its fourteenth edition, it is hardly necessary to state that it has been a standard work for many years and is familiar to all those interested in the subject concerned. Unlike works on many other subjects, scientific text-books cannot retain an important position because they were good to begin with. As the subject they deal with develops they must be revised and brought up to date, and after a time their value depends more on the labour of the revisers than on that of the original authors. Although the previous edition of this book appeared as recently as 1931, the type has been completely reset for this edition, and a considerable part of the text has been rewritten. As a result the new edition should maintain the position established by the earlier ones. The whole volume is divided into eight parts, devoted respectively to general processes, simple gravimetric estimations, volumetric analysis, miscellaneous methods of analysis, general quantitative analysis, organic analysis, estimation of gases and tables of reference. As the editors explain in the preface, the new methods of analysis which are continually being worked out are usually supplementing, and not displacing the older methods. In consequence, revision cannot be accomplished by replacement, but space for new material must be found by condensing the old. Owing to the wide scope of the book, it cannot pretend to deal fully with all the subjects included, and with so many specialised treatises available no purpose

would be served by endeavouring to make this book a complete work of reference. This applies particularly to the parts devoted to general quantitative analysis and organic analysis. The aim has been to provide an intermediate text-book which will give the senior student preliminary instruction in the more important of the special processes in which he will later be interested, and enable the graduate to revise his knowledge of the methods used in other branches of his subject. This indicates the general nature of the work at the present time. It is not an elementary text-book, a complete work of reference or a specialised treatise. It is rather a book of relatively advanced systematic instruction which deals with the basic operations, and then proceeds by easy steps from simple to difficult determinations, giving the necessary theoretical explanations as it goes on. It is thus an introduction to specialised works. With regard to the specific differences between this and the previous edition, the authors state that the additions include accounts of the estimation gravimetrically and volumetrically of aluminium and magnesium by 8-hydroxyquinoline, and the colorimetric estimation of aluminium by "aluminion," the use of the chromate radical in the estimation of barium, lead and sulphates, ferrous phenanthroline as an internal oxidation-reduction indicator, the analysis of cupronickel by salicylaldoxime and a brief introduction to the use of ceric sulphate. The section on the analysis of non-ferrous alloys has been completely revised and extended, the theoretical introductions to the various sections have been lengthened and a brief account of the theory of oxidation-reduction indicators has been included.

J. M. ROBERTSON.

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